JPRS-EST-90-002
10 JANUARY 1990

Foreign
Broadcast
Information
Service

JPRS Report

Science & Technology

Europe

ONERA: 1988 REPORT OF FRENCH AEROSPACE RESEARCH AGENCY

JPRS-EST-90-002
10 JANUARY 1990

SCIENCE & TECHNOLOGY

EUROPE

ONERA: 1988 REPORT OF FRENCH AEROSPACE RESEARCH AGENCY

36980008 Chatillon OFFICE NATIONAL D'ETUDES ET DE RECHERCHES AEROSPATIALES in English Apr 89 pp 1-276

[Excerpts from ONERA Activities 1988, detailing current projects of ONERA research departments]

CONTENTS

INTRODUCTION

This document presents the highlights of ONERA's activity in 1988. In many areas, progress was registered simultaneously on three fronts: theoretical research, numerical modeling, experiments.

The research in external aerodynamics thus offered the possibility of reducing airfoil drag by 50 percent for a transport aircraft. Meshing techniques with automatic adaptation allowed computation of the flow around a complete Airbus A 320 configuration in landing configuration, with flaps, slats and landing gear extended. The same is true for the Ariane 5/Hermes space plane assembly at lift-off as well as for Hermes during landing. In parallel to this progress in numerical methods, mention should be made of the record activity of the Chalais-Meudon blowdown wind tunnels, in particular for the Hermes program.

As concerns the internal aerodynamics of turbomachines, initial results were achieved on a Navier-Stokes computation code for 3D viscous flows in compressor and turbine blades.

In the area of ramjets, the development of combustion chambers with walls cooled by a gas film should be mentioned.

Extensive research was continued on ignition-starting of the cryogenic motors for satellite launch vehicles. Experiments are now being conducted on a model of the Ariane 5 propulsion system at the Fauga-Mauzac Center.

In the area of materials, the results obtained on superalloys for turbomachine disks and blades and on their fabrication by powder metallurgy should be mentioned. For structures, mention should also be made of the experimental validation of cracking simulation and the first high temperature multiaxial tests on monocrystalline alloys for turbine blades.

In 1988, the test activity at ONERA was considerable :

- *for the Airbus A 330 and A 340 programs, for the Rafale and for fast propeller turbojets;*
- *for helicopters, at S1MA, with the rotor facility qualified in 1987;*
- *for missiles with ramjet propulsion;*
- *for the Ariane-Hermes program;*
- *for many foreign manufacturers.*

In computer science, a Hypercube system was placed in service in 1988 for parallel computation. This experimental facility may give rise to fruitful collaboration with other research institutes. Furthermore, the activities of ONERA in artificial intelligence were grouped to increase the scope of application.

In addition to these results of ONERA's research activity, the results relative to the large testing facilities should also be mentioned. In 1988, the busiest wind tunnel was the large S1MA Modane wind tunnel which, in spite of the problem with the fan, was able to supply on time the results expected by the manufacturers. The heater of the S4MA hypersonic wind tunnel was refurbished. With the Mach 10 and Mach 12 nozzles expected for 1989, S4MA will be able to contribute decisively to the Hermes program. In addition, work was started on the F4 high enthalpy wind tunnel in 1988. This wind tunnel, which will be placed in operation in 1990 at the Fauga-Mauzac Center, will be essential (by its scope and its instrumentation apparatus) for validating aerothermal computations of Hermes hypersonic reentry.

For the ETW European transonic wind tunnel, 1988 was a decisive year with creation of the company ETW GmbH by ONERA, DFVLR, RAE and NLR.

This participation of ONERA in the ETW is part of an intense cooperation activity with the European counterparts of ONERA and with other major foreign aerospace research organizations.

The future is also being prepared by the study of new concepts and new systems. In 1988, ONERA explored new prospects in the area of radars, for operation in multitarget mode or for long range observation. In optics, real-time correction of atmospheric turbulence was achieved by associating wave surface analyzer and adaptive optics. The research conducted at ONERA in radar and optics will make it possible to design a very high resolution space surveillance station.

The year 1988 was also marked by the increase in aerospace systems research in which participate all the scientific departments of ONERA as well as the CERT and IMFL. The vast multidisciplinarity of the ONERA teams augurs well for the success of this research whose importance, like that of the theoretical, numerical, experimental research conducted at ONERA, is vital for the European aerospace industry.

The President

J. Carpentier

Jean CARPENTIER

MANAGEMENT AND ADMINISTRATION

1. BUDGET

a) CURRENT EXPENSES

NET OPERATING FUNDS	MF	%
• Ministry of Defense funding	371,0	34,4
• Contracts	693,0	64,4
• Other proceeds	13,0	1,2
Total	1077,0	

USE OF THE ABOVE FUNDS ((breakdown of activities by application)	%
• Aircraft, helicopters and aeronautical equip.	40,6
• Turbomachines	9,0
• Strategic and tactical missiles, military systems	33,5
• Space	9,3
• Non-aerospace studies	0,6
• Multi-purpose studies	7,0

b) INVESTMENTS

RESOURCES	MF	%
• Ministry of Defense subsidies	95,0	65,3
• Ministry of Transportation (DGAC) contribution	10,0	6,9
• Contribution of Régions	5,5	3,8
• Self-financing (depreciation and reserve for investment)	15,0	10,3
• Contracts (including construction of equipment left at the disposal of ONERA)	20,0	13,7
Total	145,5	

USE OF THE ABOVE RESOURCES (breakdown of program funding per center of activity)	
Test centers	
• Chalais-Meudon	7,6
• Palaiseau	8,3
• Modane-Avrieux	26,3
• Le Fauga-Mauzac	15,1
Laboratories	
• Châtillon	21,3
• Toulouse Research Center	10,7
• Lille Fluid Mechanics Institute	5,2
General facilities	5,5

2. MANPOWER

The average staff in 1988 is broken down as follows :

By sector of activity

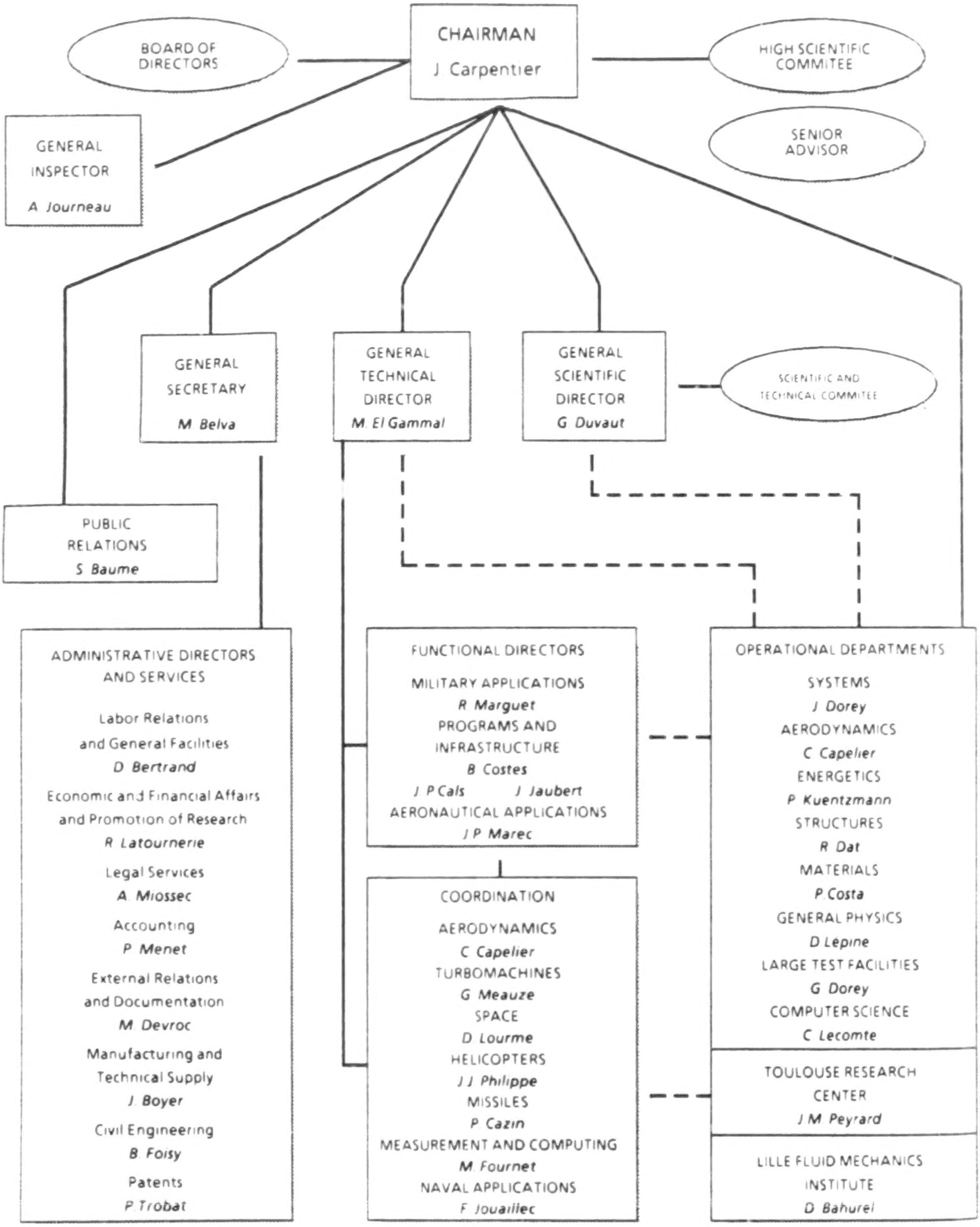
Systems	180
Aerodynamics	184
Energetics	180
Materials	107
General Physique	155
Structures	114
Large Test Facilities	322
Computer Facilities (excluding CERT and IMFL)	57
Common technical staff (SAT + TNE)	217
Executive and common administrative staff	248
CERT	244
IMFL	110
Grand total	2119

By plant

Châtillon	1068
Chalais-Meudon	252
Palaiseau	159
Modane	217
Le Fauga	69
CERT	244
IMFL	110
Total	2119

By category

Engineers and executive	986
Draftsmen, Staff Supervisors, Technicians	717
Workers	115
Clerical staff	301
Total	2119


CHAIRMAN
J. Carpentier
BOARD OF DIRECTORS
HIGH SCIENTIFIC COMMITEE
SENIOR ADVISOR
GENERAL INSPECTOR
A. Journeau
GENERAL SECRETARY
M. Belva
GENERAL TECHNICAL DIRECTOR
M. El Gammal
GENERAL SCIENTIFIC DIRECTOR
G. Duvaut
SCIENTIFIC AND TECHNICAL COMMITEE
PUBLIC RELATIONS
S. Baume
ADMINISTRATIVE DIRECTORS AND SERVICES
Labor Relations and General Facilities
D. Bertrand
Economic and Financial Affairs and Promotion of Research
R. Latournerie
Legal Services
A. Miossec
Accounting
P. Menet
External Relations and Documentation
M. Devroc
Manufacturing and Technical Supply
J. Boyer
Civil Engineering
B. Foisy
Patents
P. Trobat
FUNCTIONAL DIRECTORS
MILITARY APPLICATIONS
R. Marguet
PROGRAMS AND INFRASTRUCTURE
B. Costes
J. P. Cals
J. Jaubert
AERONAUTICAL APPLICATIONS
J. P. Marec
COORDINATION
AERODYNAMICS
C. Capelier
TURBOMACHINES
G. Meauze
SPACE
D. Lourme
HELICOPTERS
J. J. Philippe
MISSILES
P. Cazin
MEASUREMENT AND COMPUTING
M. Fournet
NAVAL APPLICATIONS
F. Jouaillec
OPERATIONAL DEPARTMENTS
SYSTEMS
J. Dorey
AERODYNAMICS
C. Capelier
ENERGETICS
P. Kuentzmann
STRUCTURES
R. Dat
MATERIALS
P. Costa
GENERAL PHYSICS
D. Lépine
LARGE TEST FACILITIES
G. Dorey
COMPUTER SCIENCE
C. Lecomte
TOULOUSE RESEARCH CENTER
J. M. Peyrard
LILLE FLUID MECHANICS INSTITUTE
D. Bahurel

AERODYNAMICS DEPARTMENT

The activities of the Aerodynamics Department are described here under two separate headings: fundamental aerodynamics and applied aerodynamics.

In fundamental aerodynamics, the purpose is to develop tools for predicting flows. The applications at hand may range anywhere from incompressible regime to hypersonic flow. The essential task is to generate computation codes that will solve the equations of fluid mechanics with different levels of approximation. That is, the potential equation and Euler equations for relatively complex configurations of inviscid fluid and the Navier-Stokes equations for simple viscous fluid configurations. For strong interactions involving separations, or for shock wave-boundary layer interactions, the viscosity effects are determined either with the Navier-Stokes equations or by inviscid-viscous fluid coupling. For turbulent flows, an appropriate turbulence model is needed for the flow in question, and the search for such a model calls for numerical simulations and experimentation.

Fine experimental analyses are also made in fundamental aerodynamics, to study complex three-dimensional flows over simple geometric configurations. The purpose of this is twofold: to improve our understanding of the fundamental physical phenomena involved, and to generate experimental data bases for validating mathematical models and numerical simulation methods.

Applied aerodynamics, on the other hand, is concerned with the adaptation of the prediction methods from fundamental aerodynamics to the specific problems of the industry, and with the validation of these methods of prediction by comparisons with experiment. In applied aerodynamics, flows around realistic configurations are analyzed to reveal deficiencies in the theoretical prediction of the same flows, or to develop semi-empirical prediction methods. Form modifications are sometimes sought, to improve performance. These studies in applied aerodynamics concern airplanes, helicopters and missiles. Part of the activity also concerns the design of new testing devices.

LEADING STAFF

Scientific Director	Claude Capelier
Assistant Scientific Director for Applications	Bernard Monnerie
Assistant Scientific Director for Research	Henri Viviand
Scientific Assistant	Otto Leuchter
Technical Assistant	Pierre Weber
Computer Assistant	Claude Jamy
Theoretical Aerodynamics 1	Philippe Morice
Theoretical Aerodynamics 2	Yves Morchoisne
Theoretical Aerodynamics 3	Jean-Claude Le Balleur
Applied Aerodynamics 1	Gérard Laruelle
Applied Aerodynamics 2	Robert Larguier
Applied Aerodynamics 3	Jean-Jacques Thibert
Fundamental Aerodynamics	Jean Délery
Experimental Aerodynamics	Jean-Pierre Chevallier
Senior Scientists	Tran Khoa Dang
	Colmar Rehbach
	Jean-Louis Solignac
	Jean-Pierre Veuillot
	Henri Werlé

TABLE OF CONTENTS

ENERGETICS DEPARTMENT

The activities of the Energetics Department cover many aspects of propulsion systems for aircraft helicopters, missiles and launchers. The work conducted ranges from basic research on fundamental phenomena to in-flight validation of engines developed in collaboration with the manufacturers to equip certain probatory or operational missiles. Schematically, the work can be grouped under the following headings:

- *study of the basic mechanisms of combustion and reactive flows,*
- *integration of models in numerical codes,*
- *experiments on engine components or real engines,*
- *systems studies.*

The research on the basic mechanisms of combustion and reactive flows requires a substantial scientific and technical investment and is predominantly analytic, theoretical and numerical. It should lead to models whose validation is based on comparison of the theoretical predictions with the measurements made under the realistic and fully controlled conditions of detailed experiments using highly performing instrumentation.

The numerical codes being developed benefit from the progress made in physics and the increased power of computers. They have increasingly ambitious goals, since they aim to simulate the operation of complete propulsion systems (rocket engines, ramjets) or complex subsystems (compressors, combustors and turbines of turbojets and turboengines).

The experiments on engine components and real engines are closely related to national system programs and are therefore closely coordinated with industry. The work conducted in this framework requires recourse to teams with a high technicity and powerful test facilities, installed and modernized with the financial support of government agencies, in particular the DEN.

The "systems studies" activity is still limited, but is called on to develop in the forthcoming years. It presently concerns hypersonic propulsion, a field where it is impossible to study the motor independently of its immediate environment (air intake, afterbody) and its integration in the airframe.

This highly diversified work is illustrated by a few examples of significant results obtained in 1988.

A first series of articles concerns numerical simulation of flows in the blades of turbomachines, in solid rocket engines and airbreathing combustion chambers.

Complex meshes are required to take into account the geometry of the interblade channels of compressors and turbines. In addition, the choice of boundary conditions to be imposed downstream of the cascades is always difficult. The programs take 3D effects into account, with or without modeling of viscous effects.

This work, primarly conducted in the framework of studies on aeronautical turbomachines, also has immediate applications to space. In particular, it was used to analyze the behavior of the flow in the turbopump inlet guide vanes of cryogenic motors during the starting phase.

Numerical simulation of solid rocket engines is illustrated by examples of results concerning erosive burning and unsteady operation. The interpretation of erosive burning, based on the intensification of heat exchanges by turbulence, led to developing a complete model which gives a good understanding of the origin of the phenomenon and explains the influence of the main parameters in a simple grain geometry. Unsteady operation of a solid propellant rocket engine was also simulated numerically taking into account the coupling between the flow and the nonlinear response of the propellant. Furthermore, the unsteady behavior of a started nozzle was analyzed in detail using an explicit finite volume method to solve the unsteady 2D Euler equations; the first application of these computations is prediction of the nozzle loss which partially conditions the engine's stability.

A major action has now been undertaken to develop a numerical simulation code for airbreathing combustion chambers in the framework of the Concerted Combustion Chamber Action (A3C). This code, called DIAMANT, should allow simulation of a 3D, viscous, reactive, unsteady flow (ignition, instabilities) in an aeronautic combustor. The initial results obtained appear physically correct and comparable with available observations. This comparison will be improved further when the development of new turbulent combustion models is completed and these models are included in the code.

Other experimental research work is described. Certain of this work illustrates the possibilities of advanced measurement facilities applied to research on energetics. Efforts are also aimed at establishing the physical bases required to validate the numerical simulation codes being developed and other work concerns qualification of new technological solutions.

The method of measuring the unsteady burning rate of solid propellants by microwaves is also applied to characterizing the response of a propellant to pressure oscillations. It appears well suited to a frequency domain between approximately 20 and 350 Hz.

Granulometry techniques were applied to analyzing the mist from a coaxial injection component representing the technology used on the Vulcain rocket engine. The correlations obtained can be directly used to model the two-phase flow in the PHEDRE code developed at ONERA to analyze the combustion stability of liquid propellant rocket engines.

Other examples of optical measurements show the advantage that can be taken of these methods for energetics studies. For instance, the CARS method was adapted to simultaneous and instantaneous measurement of the temperature and concentration of reactive species (O_2 and N_2 for example) in flames. The development of this method should provide experimental data which can be used to validate turbulent combustion models. Similarly, measurement of the local surface temperatures on rotating models by optical pyrometry supported the analysis of the influence of centrifugal effects on heat transfers in the cooling channels of turbine rotors.

The close connection between models and experiments is also illustraded by the results of the research conducted on the CRETE facility to analyze flows set up in cavities between the stators and rotors of compressors and turbines. A good agreement is observed between the observations and predictive computations for this application, of special interest to turbojet manufacturers.

The technological work conducted included a theme concerning injectable fuels with high energy performance for airbreathing propulsion. Such fuels have many possibilities and the energy performance which can be expected of them is particularly interesting.

A second example concerns the study of ramjet combustion chamber cooling by air film. The results obtained on models verified the interest of this solution for developing engines for long range missiles. The results obtained on ceramic heat exchangers in view of their use in aeronautical gas turbines are also related to this category of activities.

The "engineering analyses" are illustrated by optimization of the rocket-ramjet concept for propulsion of a future partially airbreathing launch vehicle. This work is conducted jointly with other scientific departments of ONERA, SNECMA and SEP.

This selection of the results achieved in 1988 shows the broad multidisciplinary character of the work conducted by the Energetics Department where modeling, numerical simulations, experimental work and systems studies are conducted in parallel in close collaboration with government agencies and the manufacturers concerned.

SENIOR STAFF MEMBERS

Scientific Director	Paul Kuentzmann
Assistant Director	Pierre Larue
Assistant Scientific Director for Applications	Gerard Laruelle
Technical Assistant	Yves Le Bot
Assistant to the Assistant Director	Claude Verdier
Special Assistant for Gas Turbines	Yves Ribaud
General Aerothermochemistry	Francis Hirsinger
Aerothermochemistry Applied to Chemical Propulsion	Guy Lengellé
Aerodynamics and Aerothermics of Turbomachines	Georges Meauzé
Fuels and Special Propellants	Lionel Nadaud
Ramjets	Pierre Berton
Liquid Rocket Engines and Launch Vehicles	Daniel Lourme
Measurements	Jean-Claude Demarais
Advanced Propulsion Systems	Dominique Scherrer
Fauga-Mauzac Propulsion Laboratory	Pierre-Gérard Mentré
Senior Scientists	Denis Dutoya
	Pierre Laval
	Guy Lengellé
	Pierre-Jacques Michard
	Claude Verdier

TABLE OF CONTENTS

GRANULOMETRY OF A SPRAY FROM A COAXIAL INJECTOR OF THE VULCAIN ENGINE *(CNES Contract)*

Knowledge of the granulometry of the spray from a coaxial injection element is one of the key points in study of the combustion stability of the Vulcain engine. In effect, it is an essential input for the PHEDRE unsteady numerical code developed at ONERA for CNES, following the instabilities which appeared in the Viking engine.

It appears relatively unlikely that we will be able to achieve a detailed theoretical model describing all the physical mechanisms involved and completely characterizing the spray within a time compatible with development of the Vulcain engine. This is why ONERA, in agreement with the manufacturers (SEP and MBB), preferred to use an essentially empirical and global approach consisting of supplying the chamber model with a realistic representation of the granulometry of experimental origin.

The test facility used is that set up in the Fauga-Mauzac Center (CFM) during research on the Viking engine. It mainly consists of a closed cylindrical chamber with windows allowing granulometric measurements and designed for a maximum internal pressure 30 bars of nitrogen or helium.

The instrumentation consists of a Malvern 2600 HSD optoelectronic granulometer which measures the mass distribution of droplets distributed into 15 classes with diameters from 5 to 1100 μm.

Figure 1 is a view of the test chamber showing the location of the granulometer. Figure 2 shows the control panel for the injection circuits and the computer associated with the granulometer. On the screen is displayed a typical histogram corresponding to a spray such as that of Figure 3.

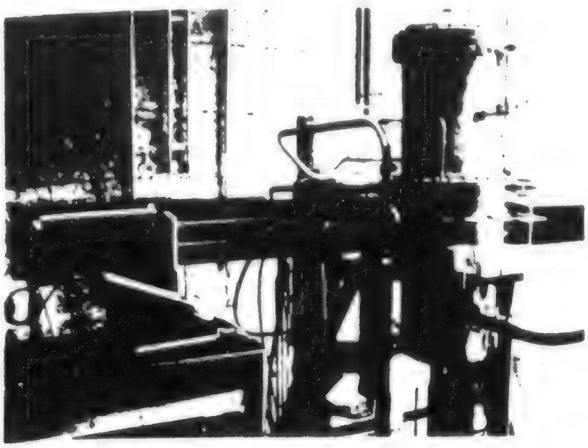


Fig. 1 - Back pressure chamber for spray tests. Granulometer location.

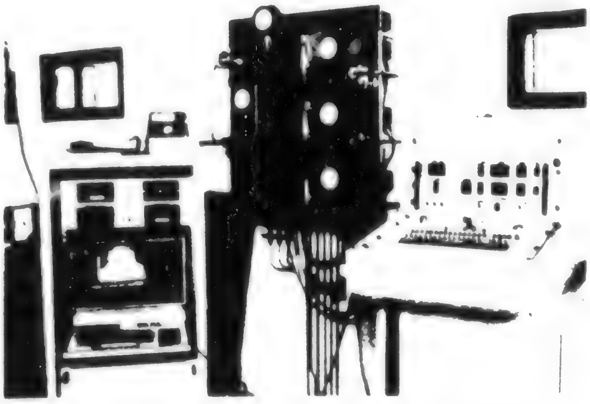


Fig. 2 - Injection circuit control panel. Computer associated with the granulometer

Fig. 3 - Appearance of the spray (chamber pressure = 20 bars)

The histograms obtained are approximated by conventional Rosin-Rammler laws with two parameters, D_{RR} (mean diameter) and N_{RR} (dispersion parameter).

We used a gradual approach consisting of initially conducting tests in water/gas simulation in various operating points. This allowed us to establish analytic correlations on each of the two parameters using the fluid injection velocities and the gas density as well as the geometric characteristics of the injectors (Fig. 4).

It can be seen that the use of two different simulation gases made it possible to experimentally investigate a very wide range of velocities and densities.

Tests with other fluids are in progress to identify the effects of quantities such as surface tension or viscosity.

The correlations obtained made it possible to restore not only the mean diameters but also a complete distribution under nominal operating conditions of the engine, suitable for use in the two phase flow computations with PHEDRE code.

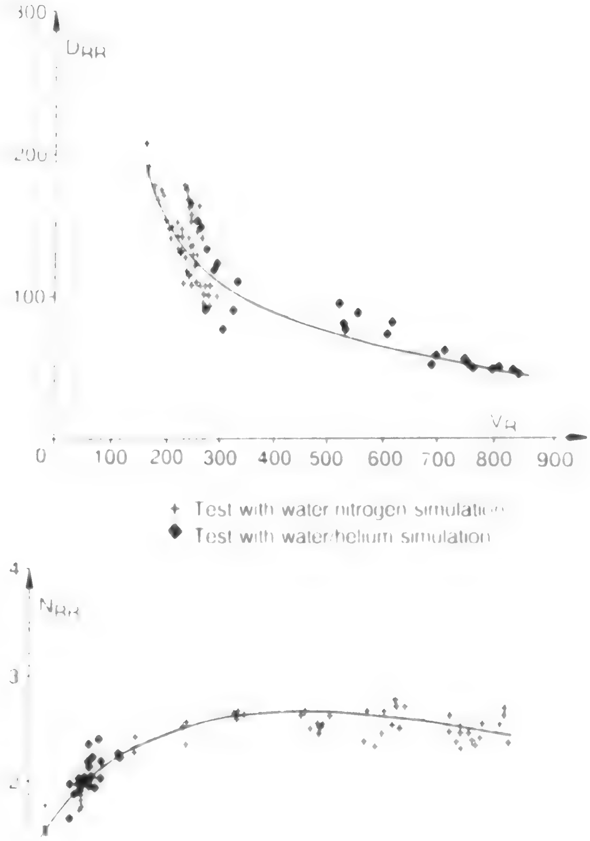


Fig. 4 - Correlation between the parameters of the Rosin Rammler experimental distributions and the variables of the operating point

L. VINGERT

SYSTEMS DEPARTMENT

The activity of the Systems Department concerns the multidisciplinary applied research of ONERA and, in particular, the study of new concepts and aerospace-oriented systems

This activity is mainly conducted under contract, in direct relation with government programs and manufacturers projects. It is clearly oriented toward military applications

The fields of research mainly include

- *aerospace mechanics for the analysis of aircraft, missile, satellite and space vehicle missions*
- *the impact of thermophysical phenomena such as kinetic heating and icing on the mission of these vehicles;*
- *the integration of new concepts in preliminary missile projects and their evaluation by ground and flight testing;*
- *the development of methods and apparatus associated with the processing of antenna array signals;*
- *radar signature analysis and the attempt to achieve stealth,*
- *the evaluation of complex active optronic systems*

The Department conducts theoretical and experimental work in these fields as well as work unrelated to applications to refine the analyses and open new prospects. The research mainly concerns optimization, aerothermics, electromagnetism, signal processing, image processing and optical computation

Certain of the activities of the Systems Department are conducted in collaboration with other scientific departments of ONERA, in particular for air-breathing propulsion and lasers, and can lead to testing on a significant scale, in particular for flight tests of missiles or building experimental radars and radar analysis stations.

A few of the most significant results obtained in 1988 are outlined below

In the area of future vehicle performance prediction, the Systems Department optimization software was applied to the trajectories of missiles, air-breathing launch vehicles and Hermes. In addition, constellations of satellites suitable both for radiocommunications and the independent navigation of moving vehicles were analyzed.

Several preliminary missile projects using a rustic ramrocket propulsion system were analyzed, pending the initiation, scheduled for the beginning of 1989, of a new exploratory development

In cooperation with Aerospatiale, a flight test allowed the concept of independent navigation of a missile with a strapdown inertial platform reset by line detection to be validated. Work continued on resetting by altitude correlation and ground imaging.

Substantial progress was made in developing the real-time computers for the RIAS experimental radar and allowed the many possibilities offered by this radar to be demonstrated. New projects using this principle are being investigated in collaboration with the government and manufacturers

The Missiles Directorate (Direction des Engins) awarded the Systems Department the contract for development of a radar analysis station to be located on a ship of the French Navy for long range target observation.

Significant progress was made in the areas of laser/matter interface analysis and nondestructive testing of structures by infrared thermography and photodeformation.

In cooperation with the Physics Department, an experiment using adaptive optics and a wave surface analyzer allowed turbulence effects to be corrected in real time for the first time in Europe.

The following pages illustrate a number of these results. It is recalled that a large share of the activity of the Systems Department falls under National Defense classification and that the research presented herein gives only a glimpse of the total activity from which significant parts are missing.

SENIOR STAFF MEMBERS

Director	Jacques Dorey
Assistant Director	Jean Fave
Assistant Director for Optoelectronic Systems	Gérard Garnier
Systems Experimentation Advisor	Jean-Claude Théodore
Scientific Advisor	Christian Marchal
Technical Advisor	Jacques Denis
Penetration Systems Advisor	Michel Staron
Aerospace Mechanics and Systems	Claude Aumasson
Thermophysics	Daniel Balageas
Radar - Sonar	Jean Appel
Signature Analysis	Joël Fritz
Missiles	Bernard Petit
Optronic Systems	René Jalin
Senor Scientist	Pierre Bertrand

TABLE OF CONTENTS

RADAR SIGNATURE EVALUTION PROGRAM

A program called APOGES (French acronym of Approximation of Geometric Optics for Evaluation of the RCS) was developed at ONERA for rapid evaluation of the radar cross section of missiles in various roll and attitude configurations.

From a reading of a drawing, the missile is broken down into simple elements whose backscattering is computed from the physical optics (shells, cones, cylinders, flat plates, etc.), the geometric optics (dihedrons, processing of concealed parts, etc.), the diffraction theory (edges, lines, diffracting loops, etc.) and empirical methods (air intakes, nozzles, etc.). The global RCS is obtained from incoherent summing of the RCSs of the various elements, allowing the average RCS to be obtained for a frequency band centered around the computation frequency.

Execution of the program for a backscattering pattern of 180 angular points in azimuth lasts approximately 20 s on the Cyber 750. Figure 1 shows the theoretical backscattering patterns (evaluated by APOGES) and those measured on a real missile. It can be seen that the maximum differences between the predicted and measured values do not exceed 4 dB.

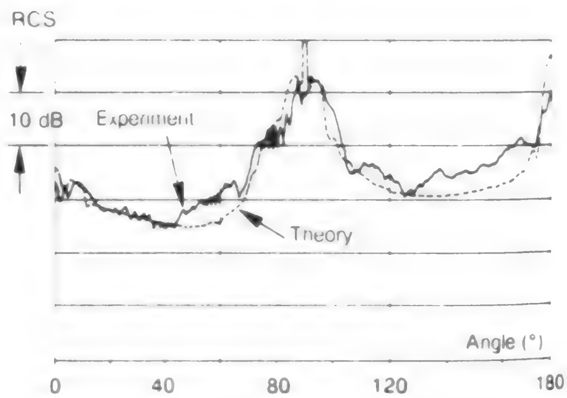


Fig. 1 - Theoretical backscattering pattern of a missile for the 4-5.2 GHz frequency band.

D. LAMOTTE

RADAR SIGNATURE OF AIR INTAKES

(Aérospatiale Contract)

In order to reduce the radar signature of aircraft and missiles, it is necessary to understand and model the electromagnetic behavior of the air intakes.

Backscattering by a circular cylindrical guide closed by a flat bottom simulating the compressor of an engine was modeled by the geometric theory. Figure 1 shows an example of the results obtained from this model, compared with the experimental measurements.

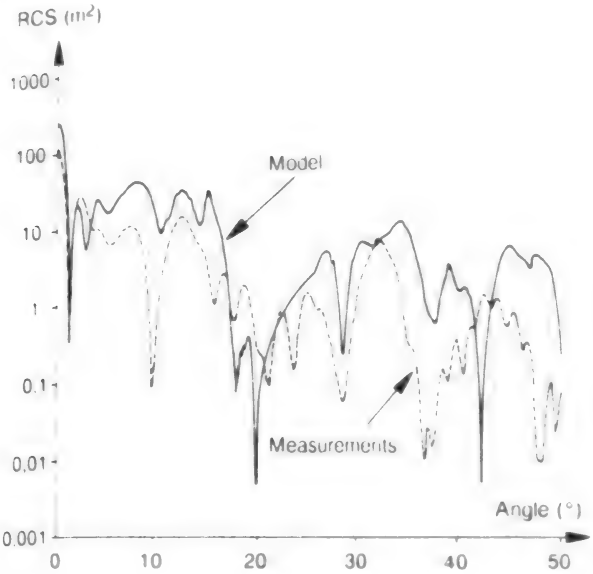


Fig. 1 - Backscattering pattern of a cylinder closed by a flat bottom.
Cylinder 0.346 m in diameter and 1 m long.
Frequency: 17 GHz.
Modeling by the geometric theory.

The RCS of a circular cylindrical guide was also modeled by the modal theory. Figure 2 compares the results obtained for a smaller cylinder with this theory and by experimental measurements (the echo due to diffraction was subtracted).

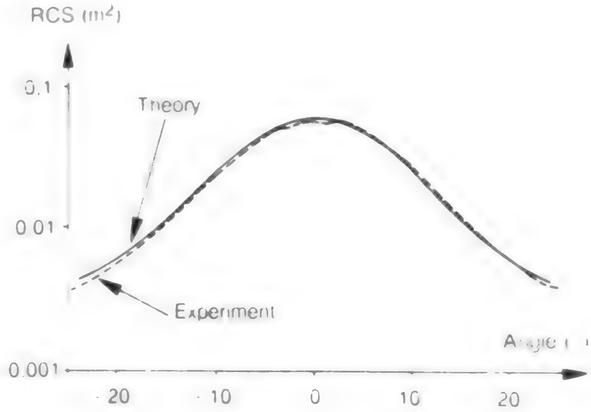


Fig. 2 - Backscattering pattern of a cylinder closed by a flat bottom.
Cylinder 0.042 m in diameter and 0.300 m long.
Frequency band: 16-18 GHz.
Modeling by the modal theory (20 modes taken into account).

Modeling by the geometric theory is limited in practice to simple geometric configurations and cannot include absorbent materials. On the other hand, considering the good convergence of modeling by the modal theory, a computation code is being developed at ONERA to obtain the set of modes in a guide of any type with a straight section covered with a stacking of various layers of absorbent materials (dielectric and/or magnetic losses). This code will allow the shape and materials of the air ducts to be optimized to achieve radar discretion.

D. LAMOTTE

MULTICRITERIA OPTIMIZATION OF ABSORBENT MATERIALS

Radar discretion of combat aircraft and missiles can be achieved in part by using coatings to absorb electromagnetic waves. The thickness, weight and withstand capability of these coatings must however be compatible with the operating requirements for such units and their costs of manufacture must not be prohibitive. The use of multilayer materials is a solution to this problem, but their definition requires the choice of a large number of parameters to insure a "satisfactory" tradeoff as regards conflicting criteria, difficult to evaluate with accuracy and in presence of the operational constraints related to the project studied.

In this context, ONERA developed a computerized tool allowing an interactive, automatic and rapid search for the best tradeoff for a given problem. A generalized projected

gradient method is used first to minimize the reflection coefficients. The nonlinearity of this criterion and the associated constraints lead to multiple local optima which are all potential solutions to be evaluated on the basis of the various criteria retained. In addition, taking the manufacturing tolerances on the materials into account leads to uncertainties on the values of the various criteria. They are combined after harmonization and their priorities and uncertainties are taken into account by suitable inference techniques. The two major approaches in this area were considered: Dempster and Shafer's evidential reasoning and the theory of possibility (Zadeh fuzzy sets). Optimization of the single synoptic criterion allows one or more solutions to be suggested to the user. In order to limit the large number of possibilities to be evaluated and compared, the initializations of the reflection coefficient optimization module are defined interactively to insure a search tree structure corresponding to the wishes of the user (Fig. 1).

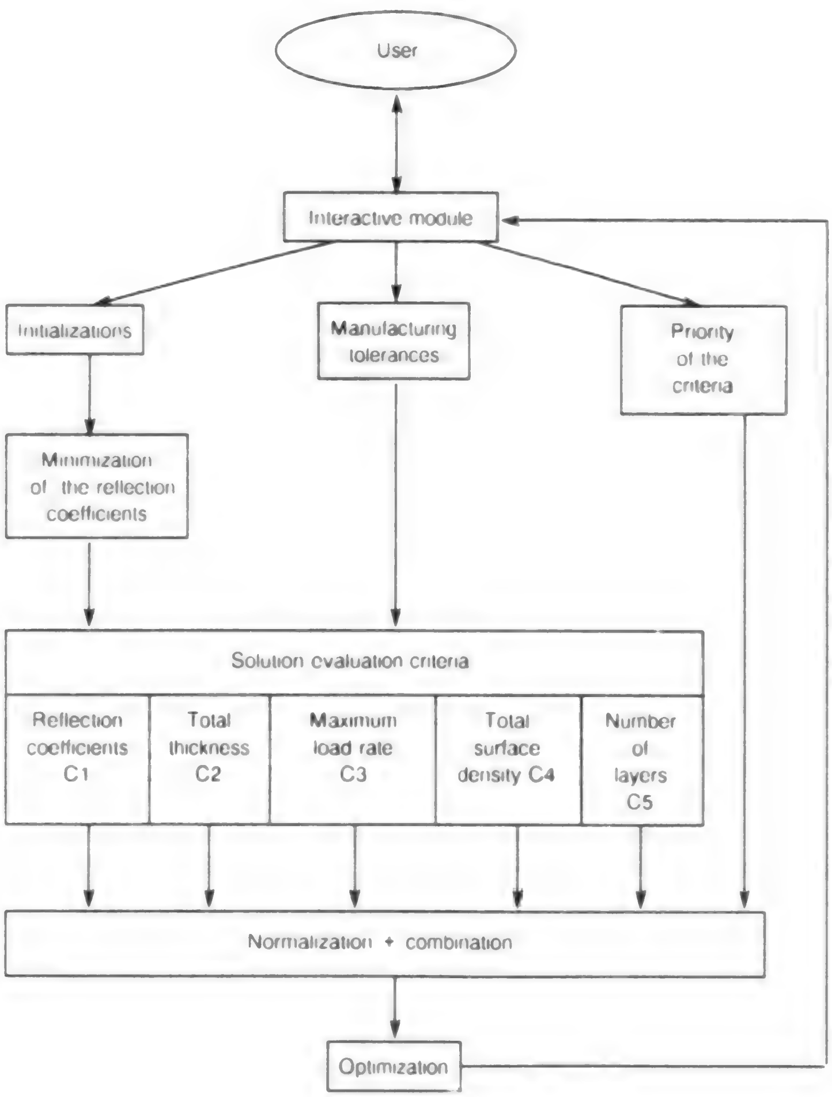
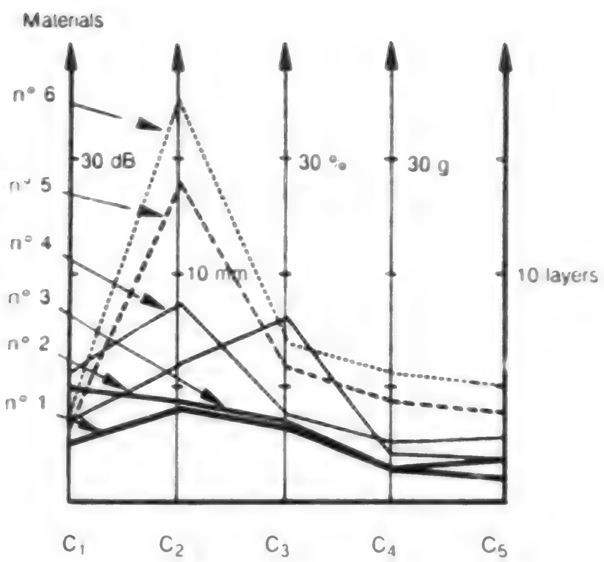


Fig. 1 - Multicriteria decision aid process.



CRITERIA	C_1	C_2	C_3	C_4	C_5	MATERIAL SELECTED
CONFIGURATIONS TESTED PRIORITIES ASSIGNED TO THE VARIOUS CRITERIA	3	3	3	3	3	n° 1
	5	2	2	2	2	n° 4
	1	5	1	1	1	n° 1
	2	2	2	2	5	n° 1
	2	4	4	4	2	n° 1

Fig. 2 - Example of use of the multicriteria decision aid process:
- *On the right: nominal values assigned to the criteria for 6 materials proposed (here C1 is to be maximized and C2, C3, C4, C5 to be minimized).*
- *On the left: choice made by the system for various criterion priority configurations (increasing from 1 to 5), taking into account the uncertainties on the criteria.*

The results obtained by the use of evidential reasoning (Fig. 2) mean that use the final system can be considered both as design aid for projects concerning radar signature mastery and for ultimate performance evaluation in the framework of a given scenario

A. APPRIOU

LARGE TESTING FACILITIES DEPARTMENT

The launching of the major A 330, A 340 and Rafale programs gave a boost to the 1988 workload of the GME wind tunnels, after the deep lull of 1987.

The busiest wind tunnel was S1MA, even though it was shut down for two months toward the middle of the year due to a fan accident. Its operating schedule even had to be stretched somewhat. By comparison, the other facilities had only an average level of activity. The S2MA tunnel is still feeling the effects of having transferred the Airbus engine system tests to S1MA (which can handle bigger models), while the heavy test programs for the A 330 and A 340 will not begin at the F1 tunnel until the end of 1989.

In civil aeronautics, aside from the A 330 and A 340 tests, we should mention the many tests for the THR turbojet with high speed propellers, Falcon 50 development testing and various tests for foreign manufacturers.

In the military field, tests were divided between the Rafale program, weapon systems under various aircraft (the weapons being carried, moved by captive trajectory system or released) and missile tests.

Helicopter rotor tests were also resumed at S1MA, on a new stand.

Finally, there were a few space-related tests (Ariane 5 with Hermes in the S2MA tunnel, Hermes escape capsule at S4MA).

As far as concerns new equipment and facilities, the most important fact is the construction of the high-enthalpy F4 wind tunnel that was started at the beginning of the year. This tunnel will be used for studying the Hermes space shuttle.

LEADING STAFF

CHATILLON

Director	Gérard Dorey
Assistant Director for Testing	Jacky Leynaert
Assistant Director for Engineering	Jean Christophe
Technical Assistant	Christian Soulier
Scientific Assistant	Xavier Vaucheret

MODANE - AVRIEUX

Head	Jean Laverré
Testing	Claude Armand

LE FAUGA - MAUZAC

Head	Jean-Marie Carrara

CONTENTS

TEST ON AIRBUS A 330 AND A 340

(Aérospatiale Contract)

Various tests were run in 1988 for the Airbus A 330 and 340 programs. Some of these used complete 1:50 scale models in the S2MA tunnel, to qualify the general aerodynamics of the airplanes and optimize certain elements such as the fuselage landing gear fairings. Others used a motorized 1:16.5 scale half model in S1MA to study the nacelle installation on the wing.

These all had to be run before tests could begin with the complete 1:19 scale model (three-meter wingspan), planned for 1989 in the S1MA tunnel.

Figure 1 shows the 1:50 model in the S2MA tunnel. For this detailed comparison of the drag in various configurations, only the fuselage-wing assembly is weighed, by an internal balance. The rudder is separated from the fuselage and serves as an intermediate element connecting the balance to a slender sting at the top, with the sting attached to the wind tunnel stingholder sector. This type of arrangement creates less of a flow disturbance on the model, all the way back to the tail cone.

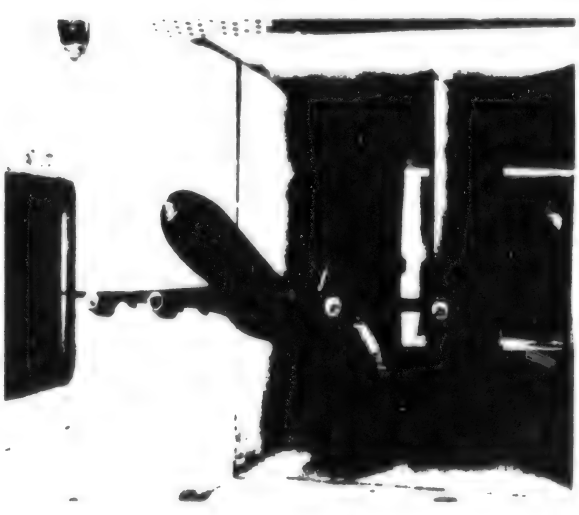


Fig. 1 – A 340 model on fin sting at S2MA.

The fidelity of the measurements can be appreciated in terms of the differences between the drag coefficients measured at different points on the base configuration, as in figure 2 where the results from twenty-nine polars are brought together from five different rotations spread out over eight days of testing. Compared to the average value, the deviation of the drag coefficient over the entire set of measurement points up to cruising C_L ($C_L \approx 0.5$) can be considered less than $\pm 1 \cdot 10^{-4}$.

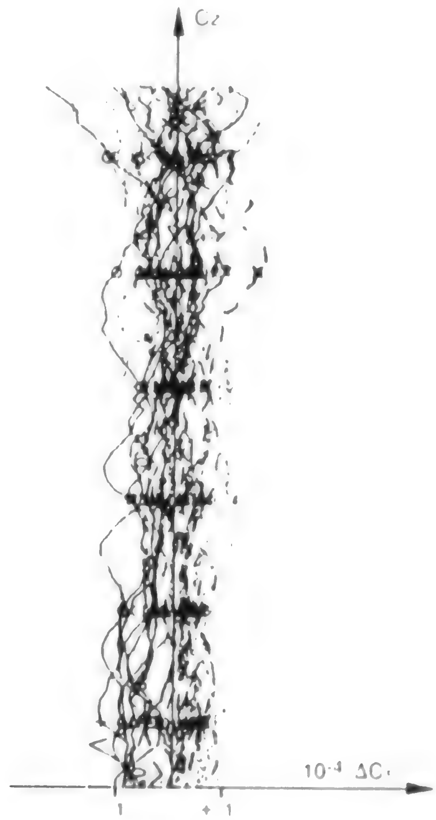


Fig. 2 – Drag measurement fidelity.

This deviation is even smaller if we average a few measurements, which is what is requested by the constructor for detailed drag comparisons. The average typical deviation for all the fidelity tests is $0.54 \cdot 10^{-4}$.

For structural reasons, the fact of holding the model by the rudder means that only the lower shape of the rudder is true. The deformation of the upper part and the presence of the sting are

taken into account in the comparative calculations of the flow over the model with and without its support

A validation was made of this type of correction in a special test using the same A 340 model with two different fin stings – the orignal one, which in fact simulated the A 340 rudder at the fuselage scale, and the "dressed up" fin to simulate the A 310 model scale.

The calculations were made by Aérospatiale, using a panel method with correction for compressibility.

Figures 3 and 4 show the 1:16.5 scale half model in the S1MA t nnel. Tests were run both with permeable nacelles and with nacelles fitted with TPS (Turbofan Propulsion Simulators) units driven by compressed air turbines.

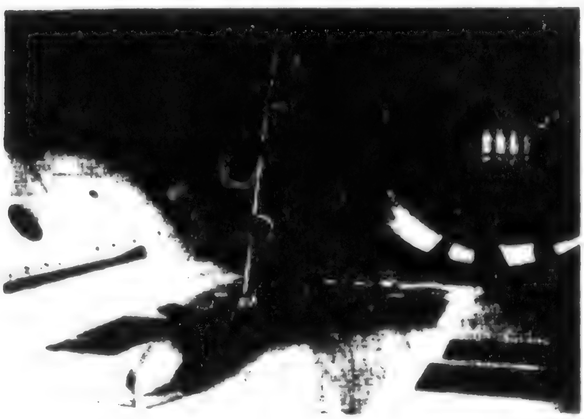


Fig. 3 - A 330 half model in S1MA (version with permeable nacelles).

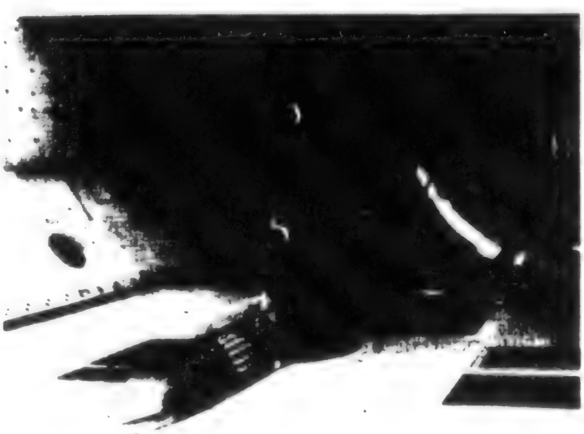


Fig. 4 - A 340 half model in S1MA (version with permeable nacelle).

The half-model is weighed by a wall balance with two co npressed air flow-through devices. The half-fuselage is separated from the boundary layer of the wall by an unweighed barge.

Fig. 5 - Fidelity of pressure distribution measurements near the nacelle.

The measurement fidelity with and without propulsion simulation is comparable to that achieved in the S2MA wind tunnel, i.e. $\pm 1 \cdot 10^{-4}$ in magnitude. The confidence is also improved by averaging numerous tests in the same configuration.

The nacelles and their pylons are equipped for pressure measurements, as are several strips of the wing to either side of the nacelles. To get very accurate pressure distributions, the small low-frequency wind tunnel velocity fluctuations, already monitored in the weighings, are taken into account by conditional acquisition of the pressures and Mach number values that are accurate to within $\pm$ 0.001.

Figure 5 gives an example of the fidelity of these pressure measurements on the wing near the nacelle, at M_0 = 0.82, and at a C_L values close to C_{Lmax}.

J. LEYNAERT, R. SELVAGGINI and J.F. PIAT

HERMES SPACE PLANE ESCAPE CAPSULE TESTS IN S4MA

(AMD - BA Contract)

On request from AMD-BA, tests were run at Mach 6.4 in the S4MA wind tunnel, to study the longitudinal and lateral stability of the Hermes escape capsule at high angle of incidence in hypersonic flow, using a 1:40 scale model (Figure 1). Various model configurations were studied.

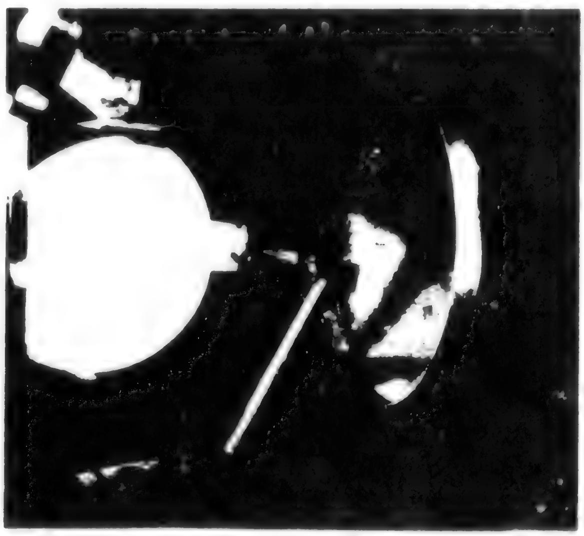


Fig. 1 – Hermes escape capsule test in S4

The models were placed at angles of incidence between - 40 degrees and + 45 degrees and at every five degrees of yaw through a range of fifteen degrees. The stagnation conditions (Pi = 32 bars, Ti = 550 K) produce the flight Reynolds number on this 1:40 model.

Fig. 2 – Hermes escape capsule model (1:40)

The model was mounted edgewise, to take advantage of the large β deflection possibilities of the wind tunnel α - β table (Figure 2).

At a pitch rate of 6°/s, two 85° amplitude polars for two values of yaw were generated one after the other during the same blowdown.

L. MARTIN

MATERIALS DEPARTMENT

The activities of the Materials Department are geared to the specific requirements of the aerospace industry. This includes research into new materials and processes, but also evaluating the in-service performance of materials already in use, and developing new physical methods for studying materials.

An important area of research concerns superalloys and includes:

- *alloys for single-crystal blades;*
- *conventional powder ($\simeq 100\ \mu m$), mainly for turbine disks;*
- *alloys derived from microcrystalline powders obtained at very fast solidification rates;*
- *methods of protecting against high-temperature corrosion and oxidation, and heat barriers.*

The goal of our research in light alloys is to improve the in-service properties of known alloys, and mainly:

- *for aluminum based materials, aluminum-lithium alloys are being studied, along with alloys rapidly cooled from the liquid phase and carbon fiber-reinforced composites;*
- *for titanium alloys, the main developments concern powder metallurgy technologies, new grades of alloys, new high-strength cast-and-forged alloys and silicon fiber-reinforced composites.*

Moreover some prospective research work has recently begun on magnesium alloys, niobium alloys and different kinds of intermetallics.

These metallurgical studies are supplemented by basic research in solid-state physics: theoretical and experimental studies on the electronic structure of alloys, to gain insight into the thermodynamics of concentrated alloys, and fundamental investigation of the plasticity of metals.

Research on composites covers ablative materials, ceramic-composites, radioelectrically transparent materials and organic matrix composites.

For these materials, study is mainly directed towards:

- *the investigation of new efficient manufacturing techniques;*
- *the optimization of composite characteristics in relation with their main components, the matrix, the fiber and the fiber-matrix interface;*
- *their mechanical and damage behavior, on the basis of the micromechanics of composites.*

It should also be noted that the Physical Methods Division, which first introduced the electron microprobe, has now developed some new equipment and is working on other systems that will extend the range of material analysis. Recently, this division undertook a joint project with the Université de Paris-Sud, to design and construct a secondary ion emission microprobe.

The Materials Department has extensive research facilities: three electron microscopes (100 kV, 200 kV equipped for X-ray analysis, and one of 400 kV, all of them being operated by a combined CNRS-ONERA research unit called the LEM (standing for "Microstructural Analysis Laboratory"); two scanning electron microscopes; two microprobes, including a Camebax; many X-ray diffraction apparatuses; a good set of mechanical testing equipment (tensile, creep, fatigue); various melting furnaces including induction, arc and electron beam devices; powder metallurgy facilities including both powder production units using either the rotating electrode process or inert gas atomization and compacting units by extrusion or Hot Isostatic Pressing (HIP); analysis equipment (nuclear magnetic resonance, IR, UV and UV-vacuum spectrometry, liquid and gas chromatography); a wind tunnel-laser system designed for ablation measurements; and a laser system (BLOX) for oxidation research.

LEADING STAFF

Scientific Director	Paul Costa
Assistant Scientific Directors	Robert Pichoir
	Jean-François Stohr
Scientific Assistant (Applied Mathematics)	François Girard
Multifunction Materials Division	Daniel Abbé
Instrumentation, Physical Measurements and Analysis Division	Bernard Daigne
Metal Alloy Physics Division	François Ducastelle
Cast Superalloys, Aluminum Alloys, Superalloys, Aluminum and Rapidly, Solidified Alloys Division	Tasadduq Khan
Coating and Metal-Matrix Composites Division	Rémy Mevrel
Senior Scientists	Bertrand Bloch
	René Caudron

TABLE OF CONTENTS

COMPUTER SCIENCE DEPARTMENT

The Computer Science Department is responsible both for implementing the central computation facilities and for research on new computer architectures and the applications of Artificial Intelligence techniques for the needs of ONERA.

The central computation facilities comprise first of all the Cray XMP18 of the "Aeronautique" computer. In June 1987, this supercomputer replaced the Cray 1S 2000 placed in operation in October 1984. This facility is shared with several partners of the aeronautics industry. In 1988, Aerospatiale/Avions stopped using the central computer as it had acquired its own supercomputer. However, new partners joined the club: Aerospatiale/Engins strategiques and Microturbo. The partners whose consumption is highest have direct access to the Cray (remote front-ending) via permanent high-speed lines. The others are connected by conventional leased lines and access the Cray through the central equipment of ONERA.

In 1988, in spite of the withdrawal of Aerospatiale/Avions, which was the largest consumer after ONERA, the total consumption increased up to practical saturation of the supercomputer.

ONERA is also a partner in the "Cray Recherche" GIE and has access to the Cray 2 of the Ecole Polytechnique. This supercomputer, with a main memory of 256 million words of 64 bits, supplements the Cray XMP18 which has only 8 million words and is more intensively used.

In 1988, ONERA consumed more than 2000 CPU hours (monoprocessor) on this Cray 2, i.e. pratically twice its consumption of 1987. This supercomputer is accessible via the central equipment of ONERA for all the users connected and, simultaneously, through the cluster of SPS9's of the Aerodynamics Department.

In 1988, the two Control Data Cyber 170/855 computers were still the main central computation equipment of ONERA (see Activities 1987 of April 1988). However, in the framework of an equipment development plan, the decision was made to gradually transfer most of the interactive load as well as the support of medium range graphic terminals to distributed equiment (single-user workstations or department minicomputers). Under these conditions, the central facilities will mainly be called upon to provide service functions such as: file support, access control, interconnection of internal or external users with the various computer departments, bulk printing and plotting jobs.

In the framework of this plan, the number of user workstations will gradually be substantially increased.

The IBM equipment supporting the CATIA software for CAD applications was added to (increased computation power and memory). In addition to an independent workstation purchased by the Physics Department, an additional graphic terminal was placed in operation in the design office of the Large Testing Facilities Department.

The Research Division of the Computer Science Department conducts applied research on new computer architectures (parallel computation) and the applications of Artificial Intelligence techniques. This research is carried out in close collaboration with the Toulouse Research Center with the general aim of ensuring that the results of the research meet the needs of the Scientific Departements of ONERA. As concerns Artifical Intelligence applications, the activities of all the engineers of ONERA, all departments and plants combined, are now coordinated by a single manager.

Concerning computer architectures, 1988 was marked by the start of operation of an Intel 32-node Hypercube. This equipment, with distributed memory and a large number of processors, is now replacing the multi-array processor system (four processors and shared memory) as experimental support system for research (see article below).

Furthermore, several applications were adapted to the Inmos 40-processor system (transputers) which was placed in operation in 1987.

For the applications of Artificial Intelligence techniques, the significant events were:

- *placing in operation of the Cray supervisory system (LEXAPO);*
- *preparation of an expert system model for assistance in fluid mechanics computation (ACACIA project).*

SENIOR STAFF MEMBERS

Director	Claude Lecomte
Deputy Director, Computer Research	Michel Enselme
Computer Center	Jean-Pierre Peltier
Technical Deputy	Guy Hanuise
Production	Yves Goudedranche
Liaison	Jacques Zeyons
Implementation	Georges Stalin

TABLE OF CONTENTS

LEXAPO - SURVEYOR: START OF OPERATION OF A CRAY XMP18 USER-AID SYSTEM

In 1988, a set of user-aid programs for the Cray XMP18 of ONERA ("Aéronautique" computer) was placed in operation.

This start of operation was the conclusion of work conducted jointly by the Artificial Intelligence Research Group and the Production Division of the Computer Center.

The configuration to be controlled in the framework of the application is illustrated schematically in Figure 1. It consists of a Cray XMP with several remote front ends, connected via high-speed Hyperchannel LANs and Transmic links.

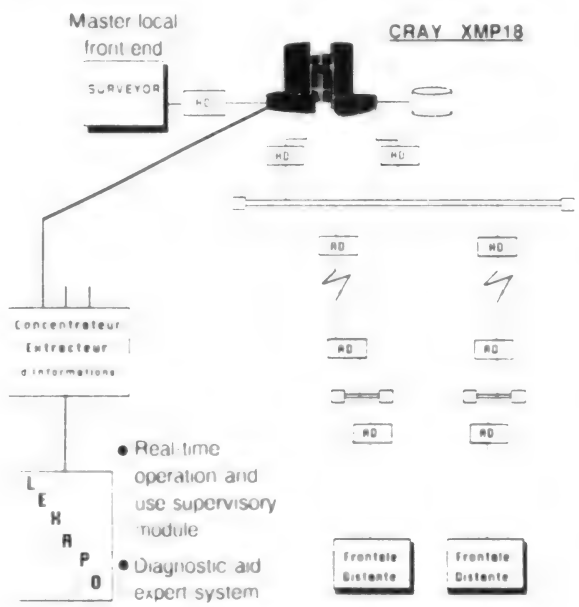


Figure 1

Setting up this configuration in an operational environment requires not only mastering the operation and use of the Cray but also a certain mastery of the links and a good knowledge of the state of the front ends connected to the Cray.

Since the supercomputer was placed in operation in 1984, the operating team has been confronted with serious problems relative to its operation:

- low visibility for the operators of events disturbing operation and use of the Cray, in particular problems on the high-speed network;
- frequent blocking of the batch jobs being executed requiring operational coverage 24 hours a day;
- no visibility for those in charge of operation except in the control room;
- a lack of expertise when problems occur.

The problems to be solved were classified in three categories: those concerning operation of the configuration, those concerning the use of this configuration when operating normally and finally those concerning the use of the configuration when operation is degraded.

Two approaches were investigated:

- one based on artificial intelligence techniques.
- the other, more conventional, based on an automaton written in FORTRAN.

These two approaches led to two products, LEXAPO and SURVEYOR respectively.

LEXAPO operates on a microcomputer directly connected to the Cray in place of a master control console.

The system consists of three sofware parts:

- a real-time supervision module written in Prolog whose functions are:
  - interpretation of the data received from the Cray via a program providing a sorting and concentration function;
  - display of abnormal events to the operator;
  - a telephone summons to an operator on call when the system is unattended.
- two failure diagnostic aid expert systems which can be consulted off line by operators in order to benefit at all times from an expertise adapted to the situation. The knowledge bases of these modules have not yet been validated by the Production Division.

LEXAPO was designed from inception to supervise operation of the configuration. The response time required was approximately one second and, in any case, better than that of an operator. However, for supervising use, much shorter response times are necessary, at the scale of the life cycle of events, which can be very short.

SURVEYOR was then designed for this. This program, written in FORTRAN, is supported by a front-end of the Cray, currently a CDC under NOS/VE, and benefits from its high processing speed. It performs three main functions:

- global information on use of the Cray: CPU activity, disk activity, memory occupation, jobs pending per class and per originating front end, active jobs;
- information concerning operation of the configuration;
- automatic reconfiguring in case of simple blocking situations concerning use.

SURVEYOR can send warning or other messages to LEXAPO which interprets them.

The SURVEYOR/LEXAPO dialog was designed to make the most of the complementary features of these two programs, expressed on several levels.

- speed of operation of SURVEYOR supported by a powerful computer allowing it to keep detailed track of execution of the jobs, and therefore use of the Cray;
- the "intelligence" of LEXAPO allowing it to interpret the information addressed to the master console and difficult to use directly. Certain such information can be sent by SURVEYOR to LEXAPO for interpretation, in which case LEXAPO returns the answer;
- implementation of LEXAPO on a micro-computer completely independent of the configuration to be supervised, which allows it to continue to "intelligently" inform the operator when the Cray or its front end is no longer operating;
- via the network supported by Cyber 860 under NOS/VE, SURVEYOR can broadcast its information to all the operating personnel concerned.

The LEXAPO/SURVEYOR pair is a good illustration of the industrial applications of artificial intelligence: artificial intelligence is not a panacea and practical solutions generally involve a marriage of reason between an expert system and conventional algorithmics, suitably dosed, in order to make the most of the respective capabilites of these techniques.

Y. GOUDEDRANCHE and J. ERCEAU

ACACIA : ASSISTANCE FOR AERODYNAMICS COMPUTATION BY AN ARTIFICIAL INTELLIGENCE COORDINATOR

In aerodynamics, numerical simulation requires solving partial differential or integral equations using numerical methods such as finite element, finite difference or panel methods.

Although the computation as such is already completely automated, there remains a lengthy process for preparing the data, which is not automated, in particular as regard the mesh structure. The advantage of numerical simulation is to allow the initial geometry of the obstacle to be modified rapidly to obtain results complying with the specifications and, where possible, optimized.

Automatic mesh generators still require fastidious preparation of the data and are therefore more like interactive "mesh editors". The user has the task of breaking the geometry of the part down into simple substructures, chaining the mesh modules and visualizing the work done.

To be efficient, a mesh must comply with certain rules known to code designers. The users therefore call on the designers of the various programs to correctly control this chaining.

The goal of the ACACIA project is to automate numerical simulation of an incompressible fluid flow on complex surfaces by a panel method as completely as possible.

This automation is achieved by the use of:

- an interactive mesh generator,
- the OA128 computation code operating on ISPC (Intel multiprocessor machine with distributed memory);
- the PYTHAGORE postprocessor which handles visualization of the computation result;
- a program using artificial intelligence techniques to supervise the system and simulating the behavior of the best user specialists of these tools.

The system operates on a SUN workstation with the computations made on the ISPC connected of the SUN by an Ethernet network.

The ACACIA demonstrator was constructed from the PTITLOO object-oriented language under LE-LISP. PTITLOO is a fast, efficient modeling tool, but the final implementation will have to be written in a

development language such as KOOL, or SMECI.

Presently, the system is capable of providing the mesh for one aircraft wing. It is to be generalized to correctly mesh any body consisting of fuselages and wings. Such objects can be aircraft, submarines, ship hulls.

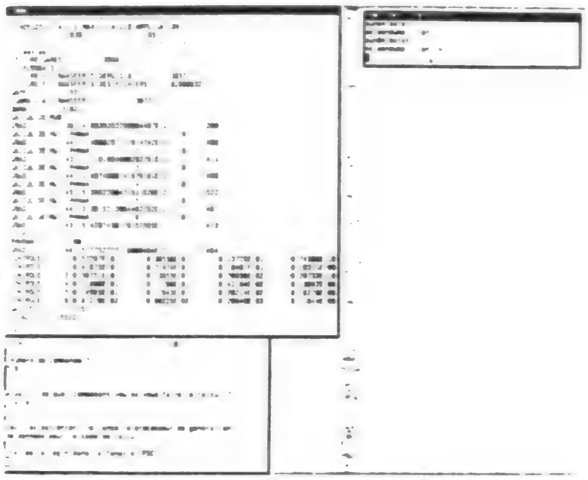


Fig. 1 - Description of the Domain

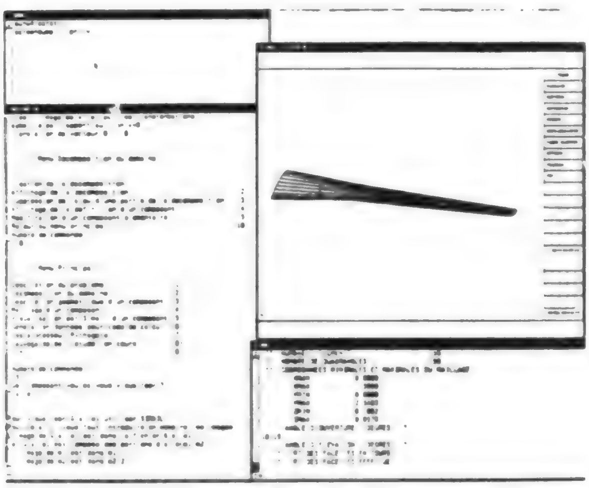


Fig. 2 - Windows Open on the Computations on IPSC

The geometric description of a wing is given as a list of profiles, each being defined by a list of points (X, Y, Z). From this description, which can be obtained by CAD, the system recomposes part of the semantics of a wing by identifying the characteristic leading and trailing edge points. It identifies accidents (rupture in slope) of the trailing edge and returns the portions of wing which will effectively be meshed. This allows the wing geometry to be closely followed.

Thus, from the breakdown into elements, the interpretation it gives of the geometric description of the elements and by requesting data on the distribution of nodes, the system generates the commands required by the mesh generator for each basic element then calls the generator to execute the operation.

During use, all the user has to do is to describe the object geometrically and use the mesh generator and postprocessor to edit partial or total views of the object before or after execution of the computation code. It is however up to the operator to log in and initiate OA128 on ISPC.

CONCLUSION

The development of the demonstrator allowed identification of problems related to the implementation of such a system and clarification of the criteria for choosing AI tools and the knowledge representation mode. One of the problems is the fact that CAD, which supplies a set of coordinates, eliminates all the symbolic and semantic information about the objects to be meshed. It is therefore necessary to restore this information.

Future research and development will concern validation of the demonstrator, the production of tools allowing experts to develop the methods themselves (in the object-oriented language sense) and the production of tools for visualizing and interpreting the results.

J. ERCEAU

TEST OF THE NEC SX-2 COMPUTER INSTALLED AT THE NLR(*)

1) DESCRIPTION OF THE MACHINE

The Japanese NEC SX-2 is a multipipeline vector supercomputer with a clock period of 6 nanoseconds. Like other scientific supercomputers, this machine has a scalar processor and a vector processor.

The scalar processor includes four pipelined functional units and has a 64 Kbyte cache memory.

The vector processor includes eight

(*) NLR : National Lucht en Ruimvaart Laboratium (NL)

pipelined units, four adders and four mulitpliers, and works on data contained in 32 256-word vector registers, i.e. a total of 8 Kwords x 64 bits. The maximum theoretical computation power of the machine, corresponding to 8 floating point operations per clock period, is therefore 1.3 Gflops.

The main memory has a maximum capacity of 256 Mbytes, i.e. 32 million words x 64 bits, and allows read and write accesses at a rate of 8 words x 64 bits per clock period. The machine installed at the NLR has a memory of 128 Mbytes.

One of the original features of this machine is that it has a control processor, the CP, separate from the array processor AP, which supports the interactive operating system, program compilations and inputs/outputs, in particular with a mass memory with a maximum capacity of 2 Gbytes, i.e. 256 million words x 64 bits.

As on nearly all Japanese computers, the operating system is very similar to that of IBM machines.

2) TESTS CONDUCTED

A number of tests were conducted on this machine to measure the effective speed of execution of a number of basic linear algebra subroutines in scalar or vector mode or the execution times of complete fluid or structural mechanics programs developed by ONERA on Cray machines, with all the data residing in the main memory in all cases.

The four basic linear algebra problems tested were as follows:

scalar (dot) product of vectors, SDOT:

$$S = S + (X(I) * Y(I)),$$

linear combination of vectors, SAXPY:

$$Y(I) = Y(I) + (A * X(I)),$$

linear combination with indirect addressing, in read mode only, SAXIPY:

$$Y(I) = Y(I) + (A * X(INDEX(I))),$$

linear combination with indirect addressing, in read and write modes, SAXPYI:

$$Y(INDEX(I)) = Y(INDEX(I)) + (A * X(I)).$$

The comparisons of the computation speeds obtained on the SX-2 and Cray XMP, in terms of Mflops, in both scalar and vector modes, are given in the table below.

MACHINE	VECTOR			SCALAR		
Vector length	100	1000	10000	100	1000	10000
	SDOT					
CRAY XMP	27	120	199	4.7	5	5
SX-2	124	525	954	15.6	15.8	12.7
	SAXPY					
CRAY XMP	42	127	156	5,9	6,5	6,5
SX-2	371	545	534	12,3	12,3	10,3
	SAXIPY					
CRAY XMP	39	102	119	3,8	4	4
SX-2	94	120	120	6,5	6,5	7,3
	SAXPYI					
CRAY XMP	33	75	85	1,3	1,6	1,6
SX-2	58	67	67	11	11,15	9

These results show that the SX-2 is between two and three times faster than the monoprocessor Cray XMP in pure scalar mode.

In pure vector mode, with indirect addressing, the SX-2 is between three and five times faster than the Cray XMP. This corresponds to the ratio of the execution times obtained for the various complete programs tested, for which the methods used were explicit, alternating direction methods on regular grids or direct methods, for finite element problems in structural computations.

However, the Cray XMP GATHER-SCATTER hardware proved to be very efficient, since the execution of loops in vector mode with indirect addressing was as fast as or even 10 to 20 percent faster than on the SX-2.

Furthermore, an important remark should be made: contrary to what could have been expected from the multipipeline architecture and double length of the vector registers, the SX-2 is relatively more efficient on short loops than the Cray XMP and therefore allows optimum performance to be reached more rapidly.

3) USE OF BLOCK SOLVING METHODS

The very high computation speeds reached for purely vector operations, even for relatively short vector lengths, give reason to believe that direct block solving methods could be very efficient on such a machine, since they allow the computations to be performed as matrix/vector or matrix/matrix operations concerning dense blocks, but small in size compared with that of the complete problem.

This idea was applied to solving a finite element problem including a 3D mesh in layers, with 50 sections, each containing 250 degrees of freedom. This corresponds to a structural computation problem for an elongated body or a flow computation in a nozzle with a total of 12,500 degrees of freedom in three dimensions.

The matrix obtained is block-tridiagonal. The LU decomposition of the diagonal blocks with dimension 250 was performed by the SX-2 at a speed of 170 Mflops. Elimination of the subdiagonal blocks, which required solving as many linear systems as there were columns in the blocks, was executed at 250 Mflops, and finally, the matrix/vector product which occurs in the block combination, at 560 Mflops, again for modest vector sizes of 250.

On the whole, the LU decomposition of this system with 12,500 DOF, associated with a 3D finite element model, required a total computation time of 7 seconds, the solution of each system then requiring only seven hundredths of a second.

4) CONCLUSION

The use of this type of methods on such machines therefore allows a considerable increase in the dimension of problems which can be considered as small in size, i.e. requiring computation times of only a few seconds and returning the result quasi-instantaneously if the work load on the machine is not too heavy.

Finally, concerning the SX-2 programming environment, the possibility of operating interactively directly on the machine, allowed by the CP, without excessively decreasing the efficiency, is unfortunately counterbalanced by an operating system with a very low level of user friendliness, making access to the programming aid tools such as debugger, optimizer or other relatively complicated in practice. Just the sight of the three enormous manuals describing the command language is enough to discourage all but the most strongly motivated users.

F.X. ROUX

IMPLEMENTATION OF ALGORITHMS ON A MULTIPROCESSOR WITH DISTRIBUTED MEMORY

(DRET Contract)

1) The iPSC2-SX: MULTIPROCESSOR WITH DISTRIBUTED MEMORY

In 1988, ONERA acquired a multiprocessor with distributed memory: the Intel iPSC2-SX. This system consists of 32 nodes configured in a "Hypercube" communication network (Fig. 1), each node being physically connected to five adjacent nodes. A node (Fig. 2) includes one Intel 80386 processor connected to a Weitek 1167 scalar coprocessor and a 4-Mbyte local memory. Programming of an application consists of distributing the data and computation processes on the nodes and organizing communications by message transfers between nodes. On each node, a "routing module" manages the message transmissions, dynamically creating the physical path for communications between nodes.

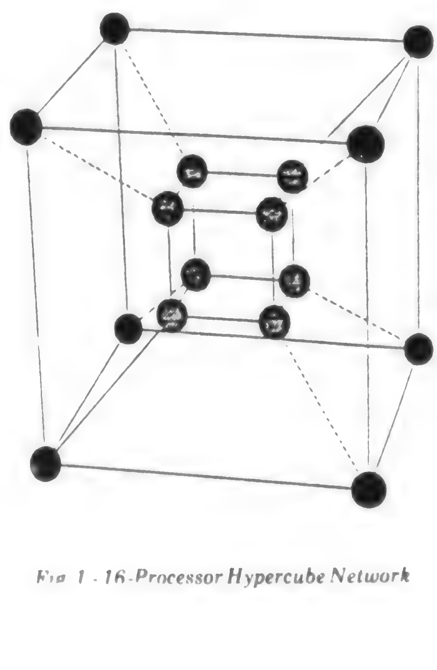


Fig. 1 - 16-Processor Hypercube Network

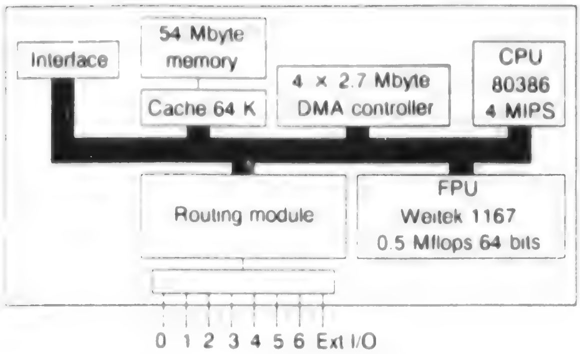


Fig. 2 - Architecture of an iPSC2-SX Node

The Weitek scalar processor has a peak performance of 1 Mflop on 32 bits and 0.6 Mflops on 64 bits. The transfer speed of the bidirectional links, managed by the routing module, is 2.8 Mbytes/s with a "startup" time per message of 350 µs.

The programming is in FORTRAN 77 or extended C using communication primitives. The iPSC2-SX is accessible to SUN workstations via an Ethernet network.

2) iPSC2-SX PERFORMANCE MEASUREMENTS

In order to develop algorithms which make the most of the capabilities of the machine, a series of tests was conducted, concerning the performance of the functional units, the computation power, the transfer rate and the memory data rate, as well as how these factors interact.

The basic test is the implementation of the multiplication of a solid matrix by a vector, duplicating the operand vector on all the processors and restoring the result vector on all the processors at the end of computation by circulation through the network. Various algorithms can be used, depending on how the matrix is distributed on the processors. Below are described the results obtained for the most efficient implementation. The matrix is stored by rows and each processor has a packet of rows. The mulitplication is made per row and the result is distributed by a sequence of exchanges from neighbor to neighbor in each direction of the hypercube. Figure 3 shows the computation rate obtained for the matrix x vector product according to the size of the vector for various numbers of processors.

If the speed-up factor for an application is defined as the ratio of monoprocessor time to multiprocessor time, the following results were obtained for a 512x512 solid matrix:

No. of processors	2	4	8	16	32
Speed-up	1.99	3.86	7.61	13.94	24.83

The degrading is due to the communication time required to distribute the results

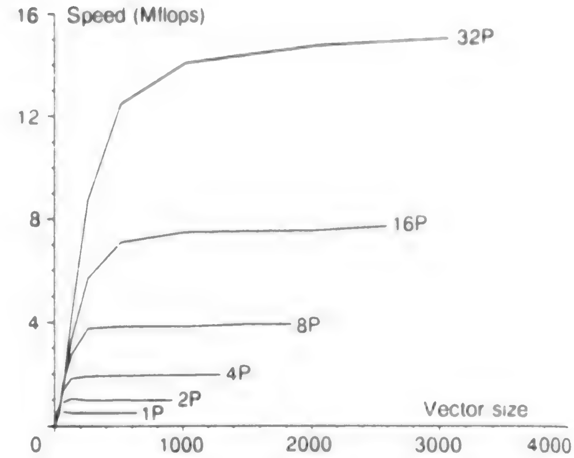


Fig. 3 - Matrix x Vector Product on a Hypercube (64 bits)

Another factor can be introduced to characterize the performance of this type of architecture, where the size of the total usable memory is directly proportional to the number of processors used: it is the efficiency, defined as the ratio of the processing times for a given application but whose size (for instance the number of points in the mesh of the domain) is directly scaled to that of the total usable memory and therefore to the number of processors. The table below shows that the efficiency of the system is preserved very well when the number of processors is increased:

No. of processors	2	4	8	16	32
Speed (Mflops)	0.99	1.97	3.93	7.73	15.02
Efficiency	0.99	0.98	0.98	0.96	0.93

3) EXAMPLE OF PARALLELIZATION OF AN APPLICATION

A code for solving the 3D unsteady Navier-Stokes equations (collaboration with LIMSI) was programmed on this system to simulate flows in a cavity one of whose walls was in movement (aimed at longer range on flows around a body). The numerical method adopted was based on a velocity V - vortex ω formulation of the equations and uses finite difference shemes and ADI methods for solving.

For this code, the parallelization technique adopted was to break the computation domain down into pencils distributed on a "logical" ring of P processors (Fig. 4), where each

processor included P pencils. Figure 4 shows the breakdown of the domain and the assignment of the pencils for an array of four processors.

Making 16 internal iterations to compute the velocities by alternating directions, the execution time obtained for this code (64 bits) per time step was equal to:

102 sec for a 66x66x66 mesh on a system with 16 nodes, corresponding to a computation speed of 4.9 Mflops;

116 sec for a 98x98x62 mesh on a system with 32 nodes, corresponding to $1.9 \cdot 10^{-4}$ sec per point and per time step and a computation speed of 9.1 Mflops.

L. MANE et S. GRISOUARD

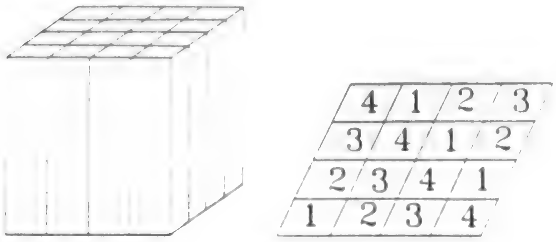


Fig. 4 - Breakdown of the Domain for 4 Processors

"GRAPHIC" ACTIVITY OF THE COMPUTER CENTER

For debugging scientific computation programs, graphic display of the results is becoming more and more important and even essential. In effect, from the synthetic display function it had some fifteen years ago, graphics has evolved into a tool necessary to the researcher for routine debugging of his programs and algorithms.

The increase in the computation power consumed by the ONERA users (multiplied by around 30 between 1975 and 1985), the appearance of 3D computations, unsteady simulations, the considerable volume of intermediate computations to be examined to debug iterative methods make graphics an indispensable tool for the researcher today who, morever, requires interactive consultation.

Since 1979, and until recently, the ONERA researchers were supported by a "unified" software allowing them to prepare the graphic part of their application independently of the graphic terminal or even of the computer used. Over time, this "3D FORTRAN" program, originated by INRIA, was enriched by relatively high level modules, making it a tool which was appreciated by the users for 2D applications.

But, as time went by, with the multiplication of workstations well suited to graphic applications and the diversification of the mainframe facilities (Cray XMP at the Computer Center, Cray 2 at the Vector Computation Center for Research (CCVR), Cyber for certain codes), it became necessary to renew the graphic software environment of the users by attempting to find programs available on the market and based on a standard, in order to ensure portability and stability of the user environment with time. The relative decrease in the manpower of the Computer Center meant that it was no longer possible to consider developments on the scale of those undertaken earlier. Thus, in 1986 the decision was taken to use the first of the existing standards for 2D applications: GKS. The first installations at ONERA took place in 1986 on the central computers of the Computer Center and in 1987 on the distributed facilities of the Scientific Departments.

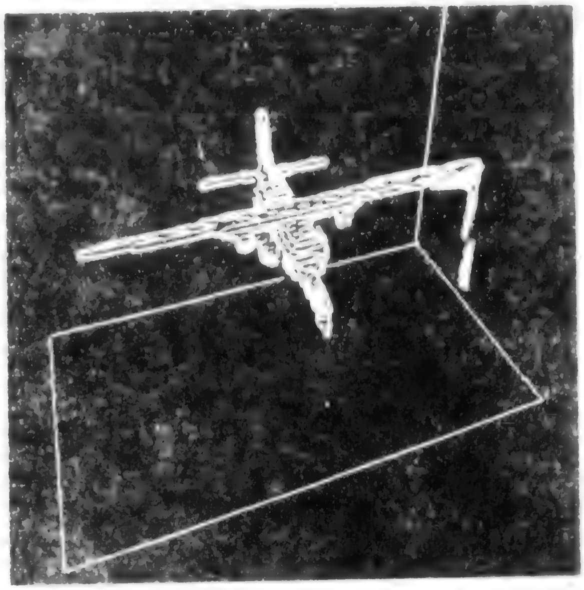
One of the initial efforts of the graphic activity in 1988 was therefore to widely distribute the basic library in the international GKS standard which was installed on more than 20 systems at ONERA and which should be used for increasingly numerous developments in the future. This library of basic functions is today supplied with a set of three interactive application programs developed by the Computer Center, allowing the user to produce graphics without requiring programming:

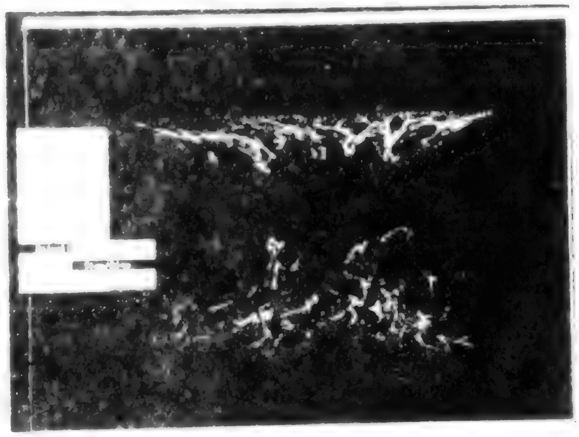
BRICE is designed to plot curves with graduated axes;

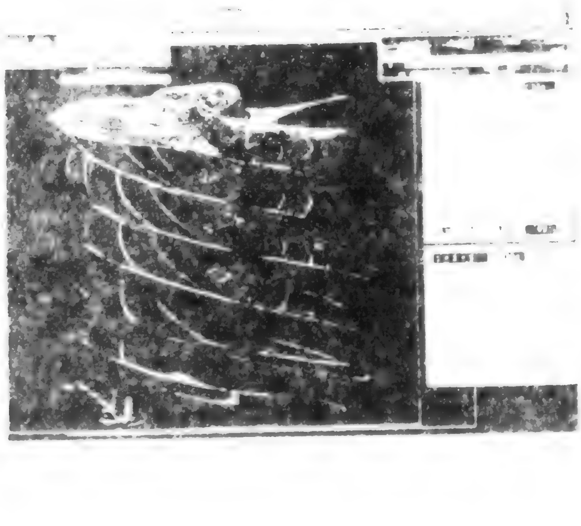
DAVIS displays fields of scalar or vector values as isovalue curves or sets of vectors;

LEA is used to create display pages including both text and graphics, which can be supplied in particular by BRICE or LEA or, more generally, any application using GKS.

Furthermore, the library of utilities of the NCAR (National Center for Atmospheric Research), offering various display tools such as







PHYSICS DEPARTMENT

The Physics Department includes a staff of engineers and physicists who conduct advanced research in scientific sectors concerning civil and military aerospace and certain other areas concerning defense.

A wide range of domains is represented in this Department. Its activity covers five major areas, corresponding to five research divisions: the Electronics and Measurements Division, the Optics Division, the Quantum Optics Division, the Acoustics Division and the Electromagnetic Environment Division.

The Electronics and Measurements Division uses its micromechanical, electronic and automatic facilities to develop measurement methods and instruments in the various sectors of application of interest to ONERA. In particular, it develops film sensors for pressure, tip clearance, temperature and thermal flux measurements, crystal oscillators for use in space, crystal and electrostatic accelerometers.

The pressure film sensor technique is widely used for studies relative to predicting the noise emitted by submarine propulsion systems. The high temperature operation of the tip clearance, temperature and flux sensors now make it possible to envision very accurate instrumentation of turbomachines. The experience gained in another area of specialty of the Department, that of electrostatic accelerometers, led to undertaking a program aimed at taking advantage of the very high sensitivity performance levels achieved with these devices to measure the Earth's gravity gradient on board a satellite (GRADIO-ARISTOTELES project of the European Space Agency).

The Optics Division has a traditional mission of assistance to the other Departments of ONERA and the aerospace industry in general, to develop and implement optical display and diagnostic facilities. More generally, it has the mission of designing and promoting the applications of optics in areas concerning defense, the CNES and industry.

In the area of optical display and diagnostics, its activity is currently strongly oriented by the necessity of solving the specific problems raised by instrumentation of hypersonic test facilities.

Another major activity of the Division concerns infrared optics, for which it has special competence in characterization of detectors under various environmental conditions and in the design of instruments using these detectors (spectrophotometer, infrared scene simulator, spectral imager, etc.).

Considerable activity is also devoted to studying the effects of the atmosphere on optical propagation and the methods designed to restore the quality of images degraded by atmospheric turbulence phenomena.

The Quantum Optics Division includes researchers investigating the fundamental aspects of laser physics, laser spectroscopy, laser/matter interaction. This activity is developed around three separate themes:

- *new laser sources;*
- *laser/matter interaction in pulsed state;*
- *Coherent Anti-Stokes Raman Scattering (CARS) and its applications.*

CARS is an area in which the Quantum Optics Division has a leading international role. In addition to basic research which has already given spectacular results for detection sensitivity (resonant CARS), the Division's activity is focused on three main themes:

- *velocimetry of gas flows;*
- *study of materials (CVD and nitriding);*
- *study of combustions.*

The Division is also very active in the area of laser sources and pulsed laser/matter interaction. In collaboration with the Energetics Department, it is conducting basic research on the chemical iodine laser. It now has two pulsed laser sources designed at ONERA for interaction studies: one dye laser emitting a few tens of joules in the visible spectrum and a KrF excimer laser with an output of some fifty joules in the near ultraviolet spectrum. The test facility also includes a vacuum interaction chamber and diagnostic equipment allowing fine analysis of the physical mechanisms involved.

The Acoustics Division, which has long been working on improving aeroacoustics knowledge and methods, has also devoted a large share of its efforts to hydroacoustics in recent years. In these two areas, it characterizes noise sources and evaluates their far field radiation; one of the aims pursued is of course to reduce noise at the source.

This mission requires coordination between experimental and theoretical work and involves both fine-tuned measurement methods and sophisticated computation programs. All the signal processing resources must be put to use by this team for wind tunnel simulation and testing under live conditions.

The Electromagnetic Environment Division works on protecting aerospace vehicles against the hazards related to the aggressions of atmospheric electricity (lightning, static electricity for aircraft and launch vehicles) and exospheric charged particles (high energy electron precipitations for geostationary satellites). Its aims are to characterize the threat (in situ measurement campaigns), study the coupling of the electromagnetic radiations resulting from the phenomenon with the sensitive parts of the vehicle (electronic circuits, computers), define protective processes and, finally, provide data to prepare standards for the manufacturers on a technically reliable basis. This is a collective approach which involves both government organizations and manufacturers and in which ONERA is associated in the fields of aircraft, helicopters, missiles, launch vehicles and satellites. The special responsibility of ONERA mainly concerns basic research on characterization of the phenomena and applied research on coupling; in the remainder of the program, ONERA mainly acts as expert and consultant.

SENIOR STAFF MEMBERS

Scientific Director	**Daniel Lépine**
Deputy Scientific Director	**André Girard**
Deputy Technical Director	**Jean Besson**
Electronic and Measurements	**Alain Bernard**
Senior Scientist	**Jacques Beaussier**
Senior Scientist	**Michel Gay**
Optics	**Jean-Claude Fontanella**
Senior Scientist	**Michel Philbert**
Quantum Optics	**Jean-Pierre Taran**
Senior Scientist	**Daniel Pigache**
Acoustics	**Gérard Fournier**
Senior Scientist	**Georges Elias**
Electromagnetic Environment	**Jean-Louis Boulay**
Senior Scientist	**Serge Larigaldie**

TABLE OF CONTENTS

ULTRASENSITIVE GRADIO ACCELEROMETER FOR THE ARISTOTELES EUROPEAN SPACE MISSION

(ESTEC, DRET, CNES Contracts)

The ARISTOTELES space project (Application and Research Involving Space Techniques Observing The Earth field from a Low Earth orbit Satellite) of the European Space Agency (ESA) aims at the accurate, global determination of the Earth's gravity field by means of a gradiometer installed on board a dedicated satellite in a low earth orbit (200 km).

A resolution of 5 mgal (1 mgal $= 10^{-6}$ G) at ground level for $1° \times 1°$ blocks (100 km on a side) is required to satisfy the objectives expressed by the scientific community of geodesists and geophysicists.

The gradiometer includes four ultrasensitive accelerometers whose measurement range is 10^{-4} ms^{-2} and whose resolution is better than 10^{-11} ms^{-2} /$\sqrt{\mathrm{Hz}}$. This instrument should allow the Earth's gravity gradient to be measured with a resolution of 10^{-2} Eötvös (1 Eötvös $= 10^{-9}$ ms^{-2}/m) for an integration time of 4 sec. The measurements will be made along the vertical and in the direction normal to the plane of the orbit.

The triaxial accelerometers, which constitute the heart of the instrument, prime payload of the satellite, are now under design at ONERA. Their operation is based on the electrostatic suspension of a high density proof-mass that is 300 grams in weight.

The configuration of these accelerometers allows them to operate in laboratory in presence of normal gravity: 1 G along the vertical axis. The other two axes, more sensitive, must be maintained around the horizontal plane so as not to be saturated.

In 1988, a first laboratory model was built around a tungsten alloy proof-mass. The accelerometer cage consists of three gold-plated silica plates ultrasonically machined to define the electrodes required to generate the electrostatic forces (Fig. 1). Metal stops are added to the electrode plates to limit the possible excursion of the proof-mass to ± 10 µm. The distances between the electrodes and the proof-mass were 30 µm for the vertical axis and 300 µm for the other two axes.

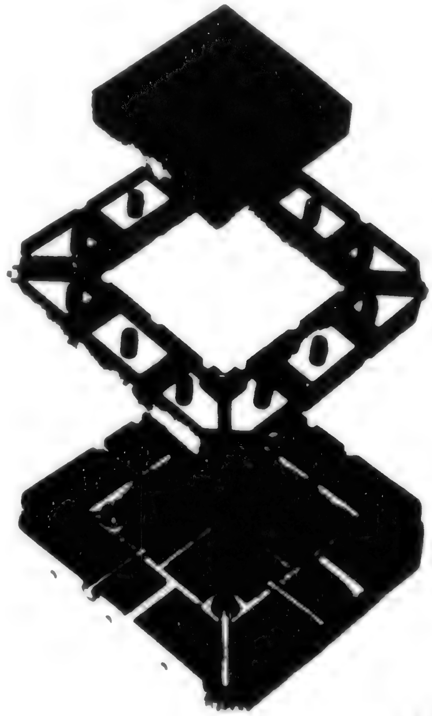


Fig. 1 - Proof-mass and electrode plates of the GRADIO accelerometer.

Figure 2 shows the mechanical assembly installed with its vacuum housing surmounted by an ion pump.

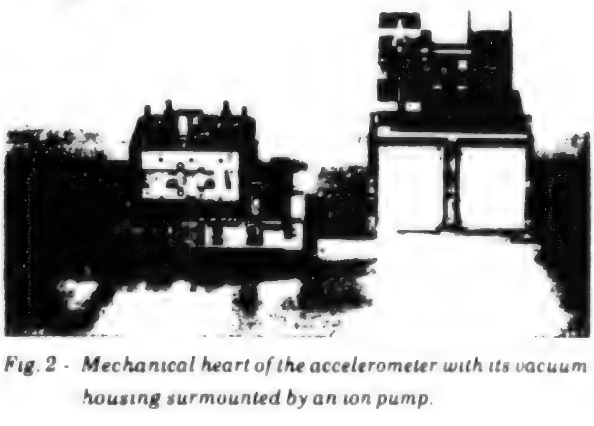


Fig. 2 - Mechanical heart of the accelerometer with its vacuum housing surmounted by an ion pump.

horizontal axes have a measurement range between 10^{-3} G and 10^{-9} G. In order to characterize the performance of such a sensitive accelerometer, it is necessary to use a test facility decoupled from seismic noise (on the order of 10^{-6} G in a "calm" laboratory) as well as slow motions of the ground (a variation of 10^{-2} arc seconds with respect to the vertical corresponds to a variation of 5×10^{-8} G on the sensitive axes).

A pendulum system, now under development, should allow the accelerometer characteristics to be observed down to a level of approximately 10^{-9} G.

In Figure 3, the measurement supplied by an accelerometer is compared with the output of an inclinometer for a variation of 2×10^{-3} arc seconds in the orientation of the pendulum plate and therefore for an acceleration step of 10^{-8} G.

This work is conducted in cooperation with SAGEM, ETCA (Belgium) and TELDIX (Germany).

In the frame work of the ARISTOTELES

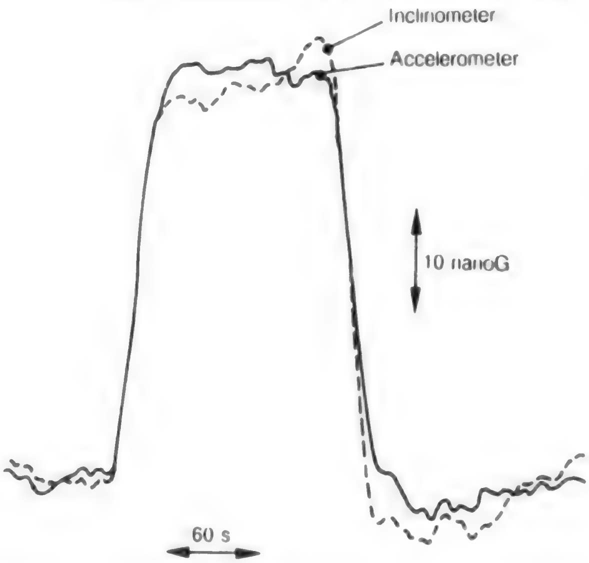


Fig. 3 - Comparison between the measurement supplied by the accelerometer and by an inclinometer.

Agency, ONERA also participated, within the industrial consortium headed by DORNIER (Germany), in the mission analysis and the design work related to the satellite configuration and to the instrument accommodation. The resolution of the accelerometric measurements to be made requires very fine integration of the instrument in the center of mass of the satellite, with thermal decoupling and a symmetrical mechanical configuration to reduce the effect of temperature variations, mass distribution variations and moving parts.

The satellite attitude control system designed by MATRA will have to be very performing and compatible with the characteristics of the accelerometers.

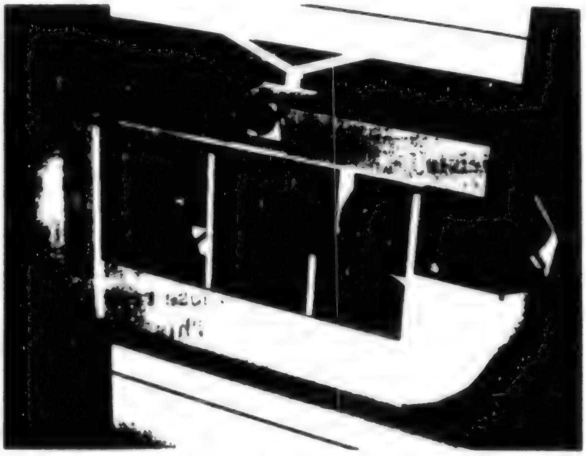


Fig. 4 - Configuration of the ARISTOTELES satellite with the plane gradiometer consisting of four GRADIO accelerometers (red) in its center.

Figure 4 shows the configuration chosen for the satellite, with a quasi-polar and heliosynchronous orbit. The accelerometers are mounted in the four corners of a plane carbon fiber structure. The calibration mechanism, composed of unbalanced wheels, occupies the center of the instrument.

P. TOUBOUL

THIN FILM SURFACE THERMOMETERS FOR TURBINE BLADES

(DRET Contract)

Work supported by DRET has been in progress for several years at the Physics Department on thin film thermal sensors usable at high temperatures.

The sensors are surface thermometers and fluxmeters designed to be deposited directly on the turbine blades.

The initial results were obtained with flat thermometer models (Fig. 1) capable of

Fig. 1 - Flat surface thermometer model.

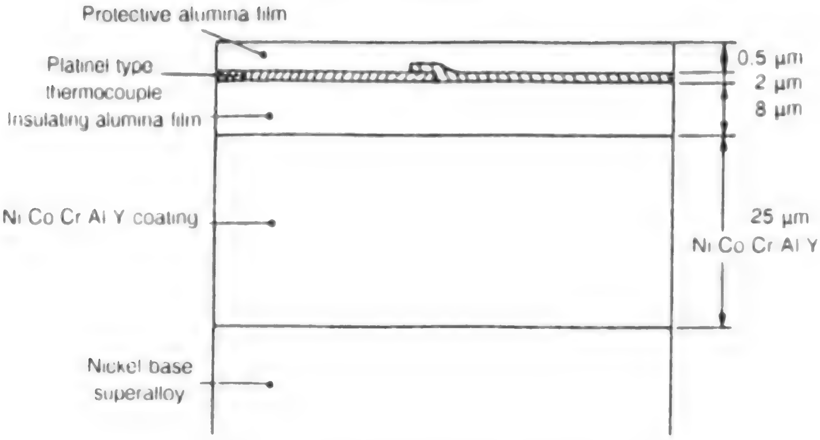


Fig. 2 - Cross section of a surface thermometer.

withstanding a temperature of 1100°C for 15 hours.

As shown in Figure 2, these thermometers consist of superimposed thin films deposited by radio-frequency cathodic sputtering on a nickel base superalloy (IN 100, DS 200, CMS X2, etc.). Aircraft turbine blades are currently made of such superalloys.

The films deposited include:

- an NiCoCrAlY alloy coating which serves two purposes: it is conducive to adhesion of the alumina film by the yttrium it contains and it improves the underlying superalloy relief;
- an electrically insulating alumina film which supports the measurement thermocouple;
- a Platinel (Engelhard trademark) thermocouple which is the actual thermometer (sensitivity: 35 $\mu V\ K^{-1}$);
- a protective alumina film designed to protect the thermocouple against oxidation at high temperature.

During this initial stage of work, the major effort concerned development of the technique for producing the insulating alumina film. In effect, during the temperature elevation which occurs during use, the alumina, which has an expansion coefficient ($\simeq 8 \times 10^{-6}\ K^{-1}$) below that of the underlying alloy ($\simeq 16 \times 10^{-6}\ K^{-1}$) can be subjected to an extension load and crack ($R \simeq 10^8$ Pa). This differential expansion effect can be compensated for by obtaining an alumina film which exhibits residual compression stresses with a specific value (2.2×10^9 Pa) at ambient temperature, thereby ensuring the capability of withstanding a temperature of 1100°C for 15 hours without degradation.

The activities currently in progress concern the development of gradient fluxmeters and adaptation of the procedures for making flat thermometers in order to equip turbine blades with uneven surfaces.

J.C. GODEFROY

STRUCTURES DEPARTMENT

The main goal of our structures research is to improve methods for predicting how aerospace structures will behave in their particular environment. This involves the aspects of structural mechanics and damage mechanics, but also in-depth analyses of the environments themselves, and how they couple with the structure in question.

STRUCTURAL MECHANICS

In 1988, the main line of activity in structural mechanics was fluid-structure coupling, both in the low-frequency range where the modal scheme finds full application, and in the medium- and high-frequency ranges.

The applications underlying this research were of three types: liquid-fuel space launch vehicles, underwater acoustical discretion and the internal acoustics of helicopter fuselages.

AEROELASTICITY

Basic research in aeroelasticity yielded computer codes capable of calculating the unsteady aerodynamics of two-dimensional transonic flows, including the static deformation in evaluating the unsteady aerodynamic forces.

The aeroelastic stability of the Ariane V launch vehicle carrying Hermes has been studied numerically and also experimentally, with a wind tunnel test on a model having dynamic similitude.

Finally, we mention here the new helicopter rotor aeroelastic stability stand that has been put into service in the S2 wind tunnel at Chalais-Meudon, and also the identification of the dynamic characteristics (for government certification) of various French aircraft.

DAMAGE MECHANICS

Damage mechanics research seeks to understand and model the main modes of degradation of composite materials as revealed by experiment, i.e. delamination, fiber-matrix decohesion and transverse cracking.

In metals, we should mention the first multiaxial high-temperature tests on single-crystal alloys – a European breakthrough. Then there is the cooperative effort between ONERA and the Université de Technologie de Compiègne to formulate a totally predictive local approach to cracking. And in computation methods, we will mention the proposal and development of a calculation acceleration process and the calculation of the V. SEP seal for the Vulcain engine.

LEADING STAFF

Scientific Director	Rolland Dat
Assistant Scientific Directors	Jean-Jacques Angélini
	Roger Labourdette
Technical Assistant	Jean-Pierre Chaquin
Aeroelasticity	Christian Soize
Structural Mechanics	Roger Ohayon
Ground and Flight Vibration Tests	Gérard Piazzoli
Wind Tunnel Model Tests	Pierre-Marie Hutin
Environment	Alain Bourgine
Special Tests	Edmond Szechenyi
Strength and fatigue	Jean-Louis Chaboche
Senior Scientists	Alain Bourgine
	Jean-Louis Chaboche
	Jean Costes
	Alain Gravelle

TABLE OF CONTENTS

AEROELASTIC STABILITY OF THE ARIANE V/HERMES COMBINATION: WIND TUNNEL TESTS *(Aérospatiale Contract)*

To confirm the aeroelastic stability of the Ariane V/Hermes "inline" assembly through the Mach range from 0.8 to 2, ONERA has designed, constructed and tested a dynamically similar 1:35 scale model that can reproduce the modes deemed most excitable i.e.:

- pitching (orbiter);
- yaw (orbiter);
- roll of the Ariane V launch vehicle with its strap-on boosters.

Figure 1 shows the model mounted on a suspended sting in the S2 wind tunnel at Modane. This type of setup eliminates the effect of parasitic modes.

The test results have already been used to choose the best launch vehicle payload fairings, check for the absence of aeroelastic instability and continue the program as originally defined, and also offer an initial database of steady and unsteady data, which are indispensable to the adjustment and validation of existing prediction models and the creation of new ones.

Fig. 1 - Hermes - Ariane model in S2MA wind tunnel.

I. CAFARELLI

CALCULATION OF THE V-SEP SEAL OF THE VULCAIN ENGINE

(SEP Contract)

The V-SEP seal is a part used at several points in the gas generator of the Vulcain engine that will be used for the Ariane V launcher. The calculation presented here concerns the behavior and the predicted lifetime up to the initation of a macroscopic crack, under extreme stress conditions.

The V-SEP seal is an axisymmetrical piece of Inconel 718 alloy with an inside diameter of 10 mm, outside diameter 20 mm and thickness 2 mm. The stresses are of two types:

- a controlled displacement when cold, i.e. when the seal is compressed in its groove;
- a cyclic temperature variation (on-off phases) when the engine is operating.

The calculation was made with the EVPCYCL code developed at ONERA, under cyclic viscoplasticity at variable temperature. This calculation combines three difficulties - variable temperature, large displacements and unilateral contact - that create variations in the elastic stiffness of the structure.

Figure 1 shows the constant axial stress on the initial geometry at the end of tightening, and figure 2 the second invariant of the plastic strain tensor on the deformed geometry at that same point in time.

The lifetime was predicted at the stabilized cycle resulting from the periodic temperature variation due to engine operation.

This calculation is a now-standard use of methods developed at ONERA. These methods are being implanted on industrial systems (SNECMA, SEP) with the new version of the SAMCEF code.

Fig. 1 - V-SEP seal after crushing: constant stresses σ_{yy} on the nondeformed geometry.

Fig. 2 - V-SEP seal after crushing: constant equivalent deformations on deformed geometry.

P.M. LESNE

SENIOR STAFF MEMBERS

Director .... Jean Marc Peyrard
Administrative Director .... Jean Lafon
Research Department Heads
- Automatic Control (DERA) .... Marc Labarrère
- Aerothermodynamics (DERAT) .... Jean Cousteix
- Computer Science (DERI) .... René Jacquart
- Systems Mechanics and Energetics (DERMES) . Patrick Hebrard
- Microwaves (DERMO) .... Florent Christophe
- Optics (DERO) .... Jean-Michel Maisonneuve
- Space Technology (DERTS) .... Manola Romero

TABLE OF CONTENTS

DERA

HIGHLIGHTS

In the aeronautic field, the main activity of the department was the identification of aircraft and helicopters through flight records :

– the identification software of lateral aerodynamic coefficients of an aircraft has been improved and its capabilities enhanced;

– a multi-transfer identification module to assist the operator in achieving a final synthesis of the modal characteristics was added to the automatic flutter data processing software developed in collaboration with the Aérospatiale Flight Test Department;

– the helicopter identification program was transferred to Aérospatiale Marignane.

– all these softwares were also used for identification of an Airbus plane in a GARTEUR project and for identification of a PUMA helicopter in an AGARD project.

An original control technique, combining a modal approach and a robustness analysis, was applied to the design of fly-by-wire controls for helicopters. The first results are very promising.

As in the previous years, seacraft activities dealt with aircraft carriers, frigates, submarines and torpedoes.

Various research was done on the nuclear aircraft carrier:

– the platform movement prediction model was implemented on the Foch aircraft carrier and the tests are due to start soon:

– the minimum pilot which ensures heading, roll and list control was certified on the free model of the vessel. Its performance was satisfactory and the feasibility of a flat turn has been shown,

– the aircraft carrier dynamic model has been experimentally certified;

– the optimum pilot is now being implemented on the free model.

The department developed a hydrodynamic coefficient identification program for submarines for test tank.

This year, the prospects for application of automatic production techniques in the aeronautic field started developing and have raised great interest by the government agencies and Aérospatiale Toulouse.

In the EUREKA Project : PARADI, the department developed a shop scheduling expert system for Aérospatiale Bourges, derived from the OPAL software. OPAL, which is still under development in the framework of the PROMIP GIP company in collaboration with LSI (Laboratoire des Systèmes Informatiques), has been selected as the backbone for a shop scheduling software package. This package will be developed in collaboration with Techlog and Aérospatiale Toulouse.

The department also developed a simulation of a sheet metal workshop for Aérospatiale Bourges involving a large number of operators and then dealing with the problem of creating "task-machine - operator" triplets.

The architecture of the flexible robotized cell of the department (CEROFLEX) is now well defined. It consists of various workstations designed to accomplish different tasks. The assembly station has been defined: it consists of an IBM Scara type manipulator, carrying the miniwrist developed in the department, with a SCOM1 control unit and the LIPS programming environment developed by AICO. The performance of the active wrist has been enhanced by a new hybrid position- force control algorithm. This system is the main component of MRT (Ministry of Research and Technology) Assembly Robot Project, in collaboration with AICO and CYBERG and plays a fundamental role in the gyroscope assembly cell of Aérospatiale Bourges.

The research on modal control took on a more practical aspect with the development of programs based on earlier research.

The theoretical research on Robust Control started at the beginning of the year. It allowed the link between the quality of the closed loop parametric identification and the robustness with respect to these parameters to be demonstrated.

The artificial intelligence activity of the department in the framework of GIA mainly concerned execution control and operator assistance.

The department has made significant progress in formalizing the planning problems and, from a more practical standpoint, a closed loop has been added in the FIGARO 2 software package.

An operator assistance model for remote manipulation in space has been implemented in the Robotics Lab of CNES (Centre National des Etudes Spatiales) in collaboration with the DIALOGICS company. The knowledge acquisition phase is now under way.

1 – PILOTING AND TRANQUILLIZATION OF THE FUTURE NUCLEAR AIRCRAFT CARRIER. ON-BOARD TESTING OF THE FREE MODEL

(STCAN Contract)

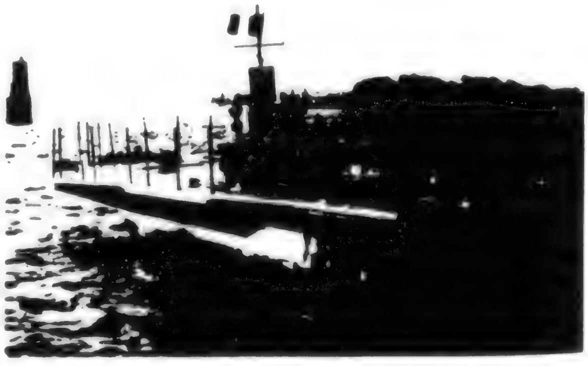
On an aircraft carrier, aircraft takeoff and landing require reduced platform movements. To improve availability of the Nuclear Aircraft Carrier (PAN) during aircraft operations, it is necessary to tranquillize it. The tranquillization actuators consist of two lateral pairs of antiroll blades and a pair of control surfaces located aft. A compensation tank system is designed to reduce the list due to wind, weight displacements and turns.

The hydrodynamic characterization of the ship, the piloting and tranquillization algorithms have to be tested at sea. For this purpose, a free model of the PAN (1:12 scale) was equipped and installed at Lorient. The prime contractor is STCAN (Service Technique des Constructions et Armes Navales). The model is currently used for conducting the tests required to validate the algorithms and qualify the future aircraft carrier

CERT/DERA, responsible for piloting studies, participated in design of the free model in defining the control system: type, number and accuracy of the sensors required as well as dimensioning of the on-board computer. These characteristics were determined in the laboratory by feasibility studies. In particular, the importance of modeling the sea in order to estimate and predict motions (two sea probes are installed in the bow of the ship) was demonstrated. To succeed in such a project, it was first of all necessary to model the ship's motion with respect to the control surfaces and waves, identify the transfer functions and validate them at sea.

The tranquillization and list control algorithms developed in the laboratory were then tested on board. The programs installed include two parts, one offline part and one real-time part. The offline part performs wave identification. For a given heading and speed of the ship, it adjusts the ship model and computes the gains required for estimation and piloting. The real-time part integrates and filters the sensor inputs (in particular, the water height on the bow of the ship is reconstructed) and supplies inputs to the actuators. The testing conducted in 1988 on the free model showed that it was possible to comply with list constraints during turns. The computer takes into account the ship's heading and speed as well as the wind direction and carries out water transfers in the compartments according to the desired turn time in order to allow a "flat" turn.

Experiments on the free model are continuing: the optimum control algorithms were installed and are being validated.



Free deck model (1:12 scale).

J.P. JUNG and G. HARDIER

DERAT

HIGHLIGHTS

The research on boundary layer laminar-turbulent transition was continued actively in various directions: for instance, in transonic flow with the aim of developing tools designed to improve aircraft drag or in hypersonic flow to determine the conditions under which transition is tripped by surface roughness on the Hermes space plane, or again in 3D flow to attempt to reproduce the influence of secondary flows.

Drag reduction was investigated by analyzing transition and boundary layer manipulators such as riblets by basic or more applied research: for instance, riblet tests on an A320 model in the Modane S1 wind tunnel.

3D shear flows (boundary layers, wakes) were investigated in several fundamental experiments on swept wings or fuselages (fixed-wing aircraft, helicopters).

The hypersonic flow theme was developed, in particular in the framework of the Hermes project: boundary layer computation methods with dissociation and ionization of the air in 2D and 3D; computation of the real gas shock layer by solving Navier-Stokes equations, stability of laminar boundary layers with compressibility effects; formation of Gortler vortices.

The T2 wind tunnel was used intensively: riblet tests; buffeting tests; laminar airfoil tests.

A major effort was devoted to upgrading and improving the technical facilities: installation of a three-component laser velocimetry facility in the T2 wind tunnel planned for the first half of 1989; establishment of a project to build a water tunnel.

Fig. 1 - Riblet tests in the MA S1 wind tunnel on A320 model. Work conducted in collaboration with the Aerodynamics Department, Aerospatiale and 3M.

DERI

HIGHLIGHTS

In COMPUTER SECURITY, the activities concerned the theoretical bases of the model for Multilevel Security (MLS) and its uses: hardware mechanisms, basic software and operating system, networks, software engineering facilities and finally data bases.

In spite of the wide range of these applications, the interrelations between the activities were intensified through the common theoretical basis. The work in these areas of application has sufficiently progressed to plan the production of hardware and software models (MLS processing unit, UNIX, local network).

In PARALLEL MACHINE ARCHITECTURES, the work conducted on high performance digital architectures investigated two approaches;

– the first is based on implementation of the concept of reconfigurability of the interconnection structure of a large number of processors. A model was built with eight T414 transputers. An extension to 32 processors and more is planned for 1989. The programming model used is OCCAM;

– the second concerns architectures with a hierarchical structure aimed at taking advantage of local processing, with the processor coupling topology remaining frozen. The program development system was defined around the LDCT language and is now being produced and validated using an emulation on a four- processor SPS7.

The study of parallel architectures also concerns architectures designed for efficient execution of functional languages and, more generally, languages designed for symbolic processing. The Symbolic Reduction Machine (MaRS) project should lead in 1989 to the production of a prototype which can be used as coprocessor with a host machine.

In ADVANCED INFORMATION PROCESSING, the research themes concerned:

– logic and data bases. The work in progress led to particularly significant results in implementation of cooperative systems and the management of incoherent data bases and incomplete data bases;

– research and development of artificial intelligence tools and applications. These activities are carried out in collaboration with DERA and DMI within the Artificial Intelligence Group (GIA). The research concerns neural networks and the problems of modeling the reasoning process. Development was continued on SYLOG (logico-functional programming). An efficient portable version is now available. The applications (planning of space missions, on-line diagnostics for aircraft maintenance, robotics, etc.) allow the basic research and the tools produced to be validated.

In NUMERICAL ANALYSIS, the Numerical Analysis Group (GAN) conducted studies and research on solving partial differential equations by the finite element method. Fluid mechanics and electromagnetism are the two areas of application of these theoretical activities.

In SOFTWARE ENGINEERING, the activities were conducted in the framework of two projects of the ESPRIT 1 program: TOOLUSE (due for 1989) and REPLAY (due for 1990). These two projects concern the formalization of software development. TOOLUSE defined a language, DEVA, in which the development methods are described. REPLAY uses this language and the descriptions of these development methods to evaluate their impact in software development reuse situations.

DERMES

HIGHLIGHTS

UNSTEADY FLUID MECHANICS

The research activity on unsteady shear flows was mainly materialized by the implementation of an LES type computation code (Large Eddy Simulation) based on the use of a very performing scheme allowing numerical diffusion effects to be limited and controlled. This computation tool was tested successfully on various shear flow geometries.

At the same time, DERMES continued to develop semiautomatic visualization acquisition and processing methods associated with this type of flow: 3D particle tracking, spectrum analysis of interface movements, etc.

Flow metering remains an important theme in the Department and particularly demonstrates its international collaboration: participation in the EEC intercomparison operation (laser anemometry, computation), basic research on orifice plate flow metering (contract with Gas Research Institute). Particularly interesting comparisons between experimental and computed results were also achieved on vortex flow metering (Random Vortex Method RVM).

MEASUREMENTS

In hydroacoustics, DERMES continued to devote a large share of its activity to developing measurement methods suitable for use in radiated noise reduction programs (power measurements, response of sensors under the boundary layer). In particular, successful intercomparisons demonstrated the feasibility of source power and location measurements in a very confined space.

Image processing associated with flow visualizations or object tracking is still a major activity of the Department with many spinoffs for the research conducted at DERMES (shear flows, flow metering, heat transfer, two-phase flows, study of combustors) and for the instrumentation of various test facilities (IMFL vertical wind tunnel, Test Basin, surface-effect ship, etc.). A necessary supplement to conventional measurements, the processing of images obtained by flow visualizations also has the advantage of supplying results often obtained in real time in a form directly comparable to that resulting from computations.

ENERGETICS

In the area of research on combustors, the approach developed at DERMES in which isothermal simulations are associated with various computation methods remains a privileged analysis tool whose predictive character was particularly well confirmed by the success of the Tristan operation.

Experimentally, the progress made in image processing was placed at the service of various research efforts aimed at giving a particularly detailed description of certain physical mechanisms required for modeling combustors. As an example can be mentioned:

– studies on injection phenomena: injector granulometry, study of the droplet formation mechanisms, droplet impact on hot surfaces,

– measurement of the heat exchange coefficients on combustor walls by active IR thermography.

Furthermore, pursuing the activity started in 1987, the Department continued experimental work on its pilot flame installation: temperature measurement, flame front visualization.

Finally, again in the area of heat transfer, DERMES was able to extend its heat exchanger activity in 1988 by studying cases in presence of boiling.

DERMO

HIGHLIGHTS

The activities of DERMO (Microwave Department) in 1988 were mostly related to military radar applications, which is why the discussion below, restricted to the unclassified aspects, only partially reflects the work performed and its significant points.

ANTENNAS AND RADIATION

This theme covers research activities in electromagnetism, such as the evaluation of new concepts or the development of analysis methods, as well as the development of antennas and characterization of radar signatures.

Work was started on signature modulation processes which could disturb radar operation during the detection, tracking or identification phase to supplement the range of countermeasures available for electronic warfare.

Signature measurements made on a model in an anechoic chamber and on real vehicles in the field mainly concerned tanks.

The work started several years ago on periodic arrays applicable to discrete radomes was continued.

An initial validation of the goniometry concept by processing the wave diffracted by the rotating airfoil of a helicopter was obtained by experimentation in an anechoic chamber.

INTEGRATED DEVICES

The analysis of millimetric phase shifters in a dielectric waveguide disturbed by micromovements of a piezoelectric blade was completed by taking various dynamic effects into account: sensitivity to vibrations, response time to a step. The difficulties due to mechanical resonance at a high overvoltage for a frequency of a few hundred to a few thousand hertz were identified and partially overcome.

The definition of a 35 GHz phased array model was started, for which an optimized phase shifter configuration is being studied as well as the radiating components compatible with the dielectric waveguide and with a quasi-optical pillbox type power supply; a single plane scanning model is now being built.

The study of phase shifters in a ferrite waveguide resulted in building a validation model operating in the Ka waveband which demonstrated very encouraging performance characteristics.

Study of modeling of composite ferrite/dieletric resonators for tunable filters in telecommunications led to a relatively good agreement with experimental results and continuation of the work by a manufacturer.

The completion of installation and initial operation of the clean room and its equipment for production of microelectronic circuits is to be noted.

MATERIALS AND MEASUREMENTS

In the area of characterization of the radioelectric properties of materials, the basic research on composite modeling is being continued; computerized tools were developed and applied to various families of materials, prepared and characterized for this purpose; a DGA long duration study project was also carried out at MIT on a related subject.

The facility for characterizing plane specimens in focused Ku band waves was used for this study of composite materials as well as for many other activities. It is still being perfected by developing the methods best suited to each class of material and setting up special instrumentation.

Study of the possibilities of nondestructive testing using millimetric waves also allowed an X/Y platform with a large excursion (1 m x 1 m) equipped with a 94 GHz FM-CW radar to be developed. Evaluation of performance (depth of penetration, resolution, dimensions of the smallest detectable defect) by this facility was carried out for a few dielectric materials, in particular glass fiber reinforced resin which may be used for the hull of mine hunters.

DETECTION SYSTEMS

The planned space activities (radiometric observation of the ground or sea in particular) were postponed. However, work on building active millimetric systems was developed. In particular, the model of a radar scene simulator for homing systems entered the integration phase in the laboratory.

DERO

HIGHLIGHTS

OPTICAL CHARACTERIZATION OF AEROSOLS

This action was continued in particular with real-time granulometry adapted to evolving media, the granulometric probes for meteorological applications and the optical behavior of artificially created aerosols.

RESEARCH AND DEVELOPMENT ON LASER SYSTEMS

This action was materialized by the emergence of themes such as single mode optical fiber Doppler kinemometry and high power laser diodes with an external cavity, whose results should be beneficial in the future to other projects such as anemometry, velocimetry and terrain contour recognition.

EARTH OBSERVATION SYSTEM IMAGE QUALITY APPRAISAL

The work carried out for SPOT 1 (evaluation, acceptance and operational follow-up of the radiometric and geometric performance (FTM) of the HRV camera) will be repeated for SPOT 2 scheduled for launch in 1989 as well as for SPOT 4 and HELIOS which are in the preliminary phase. Still in the area of space, it can be noted that work was halted on the application of lasers to experiments in space, motivated by a reflection on the objectives and means to be implemented for design of atmospheric probing systems for manned flights.

OPTICAL SYSTEMS FOR INFORMATION AND POWER TRANSMISSION

The network application is the highlight of this theme, with the study of the properties and processes for characterizing and monitoring short haul networks for military, aeronautical and video communication applications. The good results obtained by optopyrotechnic initiation based on laser diode and optical fiber should also be stressed. This action is described in the first article hereafter.

OPTICAL AND OPTOELECTRONIC SYSTEMS

New themes such as tomoholography or holography with a limited depth of field and speckle interferometry were added to the field consisting of the RADAC action (Attitude and Deformation Recovery by Crossed Anamorphosis) conducted jointly with DERA and HERMES and the characterization of receivers designed for aerial photography.

PARTICIPATION IN DESIGN AND CHARACTERIZATION OF LARGE TELESCOPES

The feasibility study of a single-mode optical fiber synthetic aperture telescope was undertaken as well as the possibilities for controlling the surface of large mirrors in space.

APPLICATION OF OPTICS TO NUMERICAL COMPUTATIONS

The MILORD project conducted jointly with DERI has reached the operational phase after development of the components and is the subject of the second article below. This project allowed the start of the optical computation activity with the beginning of a one-year period of a DERO engineer at the UCSD (University of California at San Diego) on photorefractive crystals and the beginning of participation on the MOTS (Optoelectronic Matrix for Signal Processing) project.

1 - OPTOPYROTECHNIC INITIATION BY LASER (IOPL)
(SEP Contract)

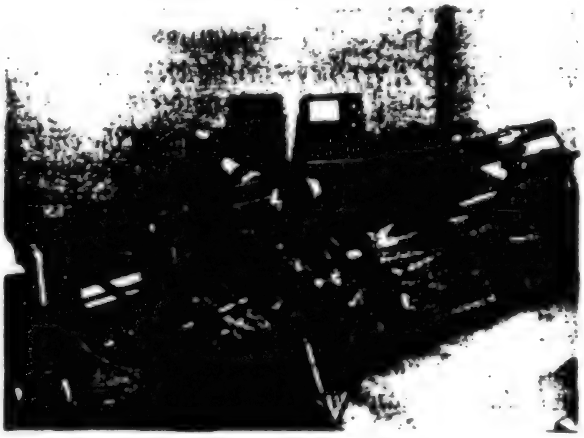
In collaboration with SEP (Société Européenne de Propulsion), DERO worked on development of an IOPL (optopyrotechnic initiator by laser) designed for initiation of pyrotechnic substances.

During the initial phase, the possibilities of optical radiation in this domain were determined using an Nd:YAG laser in blocked mode, providing a 100 ns pulse at a wavelength of 1.06 µm for various initiator compositions.

As the results were encouraging with this type of source, during the second phase it was attempted to reduce the required peak power by increasing the pulse duration in order to evaluate the possibilities of using laser diodes, which have the dual advantage of better efficiency and smaller size compared with conventional lasers.

The results were positive, since a pulse duration and output power compatible with capabilities of available power laser diodes in an array, with a maximum power of approximately one watt, were determined using an Nd:YAG laser. The spot focused on the initiation composition is determined by the diameter of the optical fiber carrying the laser flux, equal to 100 µm (photo).

The next phase corresponds to development of a laser diode IOPL with optimization of the laser diode power and the laser diode/optical fiber and optical fiber/initiation composition couplings.



IOPL experimental apparatus.

J.P. BOUZINAC

2 - MILORD PROJECT *(DRET Contract)*

The MILORD project (Multiprocessor Interconnected by Dynamically Reconfigurable Optical Links), the result of collaboration between the Computer Science and Optical Departments of CERT, is planning to interconnect eight transputers with four bidirectional links each using an optical crossbar switch in free space for the DRET.

In addition to its traditional advantages such as high bandwidth and immunity to electromagnetic interference, optics should, by its high degree of parallelism, contribute an additional gain in computer processing power, by the interconnection of a large number of processors.

In the MILORD project, each processor output link is connected to the modulation circuit of a transmission device using a laser diode coupled to a multimode optical fiber.

The principle of the network is based on a vector/matrix product in the plane of a liquid crystal spatial light modulator. The vector is formed by the alignment of the fibers imaged on the active surface of the modulator which is optically conjugated with an array of 40 independent photodetectors connected to the processors.

A ninth processor, the host, is used for communication with the user, loading and synchronization of the processors and network reconfiguration by means of a CRT. This special processor has two links on the network, which means that 34 communication channels can be set up in parallel.

Operation of a partial network including four communication channels with a data rate of 10 Mbps, corresponding to that of the processors used, was demonstrated. Integration of the complete system is now in progress.

Optical network.

M. FRACES

DERTS

HIGHLIGHTS

CHARGED PARTICLES AND INDUCED ELECTRIZATION EFFECTS

The activity of this group concerns evaluation of the fluxes of charged particles received by orbiting systems, computation of the interaction of these particles with the material comprising these systems (dose and shielding computations) and analysis of the induced charge states as well as the associated risks of discharge.

In 1988, a major effort was made to take into account the effect of cosmic radiation to which on-board logic is becoming increasingly sensitive as the performance is enhanced. A program was developed to evaluate upsets due to the nuclei created by the nuclear reactions produced by the fast protons of solar flares.

An experimental system (SIRENE) was developed to study the potential states induced by a space environment with high energy electrons (250 keV).

Solar generator degradation scenarios involving multiple causes were imagined in the framework of a contract with the European Space Agency, with the collaboration of Aerospatiale and the German firms PTS and AEG.

ELECTRONIC COMPONENTS

The activities of this group are aimed at satisfying the reliability requirements for space components of which larger scale integration and higher speed are also required.

The methods developed in previous years for characterizing the homogeneity of AsGA wafers, or more generally III-V and ternary materials, were extrapolated to industrial use. A device used to produce mobility and Hall effect maps under probes for temperatures of 100 K and above was imagined and produced, and a patent application has been filed for it.

Work on VLSI components is proceeding as planned. In addition to the CNES which actively supports this development, Crouzet, ATES and Electronique Serge Dassault have taken advantage of the capacity established in recent years. Furthermore, an experiment on the effects of heavy ions on memories is carried on the ARAGATZ Franco-Soviet flight.

COATING AND STRUCTURAL MATERIALS

In 1988, installation of the CASOAR orbital atomic oxygen simulation facility was started. It is supported by the CNES, DEN, DRET and the Conseil Régional Midi-Pyrénées.

Experiments on exposure of materials to the space environment - atomic oxygen and micrometeorites and debris - were developed in collaboration with CNES and carried on ARAGATZ. They will be recovered in 1989 after staying at least six months in space.

The Franco-Soviet project for exploration of the planet Mars by balloon is technically very ambitious as concerns the performance required of the aerostat. The CNES made wide use of the capabities of the CERT to progress on this program, both for evaluation of the materials and for conducting tests on complete balloons.

LILLE FLUID MECHANICS INSTITUTE

The activity of the IMFL is deployed in a wide range of competences related to the mechanical sciences. In many cases, it is carried out in close collaboration with the other Scientific Departments of ONERA or the CERT.

In 1988, the IMFL continued work started previously. The following research activities were developed in particular:

- *Under the responsibility of the Flight Mechanics group, development of a light aircraft spin analysis methodology, synoptic studies on the behavior of aircraft at a high angle of attack with completion of the synopsis of Alphajet operation, work on the dynamics of underwater bodies.*
- *Under the responsibility of the Structural Mechanics group, research on the dynamic behavior of helicopter blades which gives rise to design and production of models for wind tunnel testing in Chalais and Modane, the design of an initial flexible wing model for the business jet with large aspect ratio, the development of methods for characterizing viscoelastic and composite materials.*
- *By the Fundamental Fluid Mechanics group, modeling of airborne weapon firing phenomena by equivalent explosions, development and refinement of ultra-high-speed optical techniques usable in aerodynamics and hydrodynamics.*
- *By the Applied Fluid Mechanics group, wind tunnel evaluation studies on models of underwater bodies or surface ships (nuclear aircraft carrier).*

SENIOR STAFF MEMBERS

Director	Daniel Bahurel
Administrative Director	Jacques Dujardin
Flight Mechanics	Robert Verbrugge
Structural Mechanics	Francis Dupriez
Fundamental Fluid Mechanics	Arthur Dyment
Applied Fluid Mechanics	Pierre Bailleux
Design Office and Shops	Marc Deschamps
Computer Science, Electronics, Acquisition	Alain Govaert

TABLE OF CONTENTS

- END -

END OF FICHE

DATE FILMED

26 Jan. 1990